

# An 8-factor model for evaluating crew race performance

Jeffrey Cornett<sup>1</sup>, Pamela Bush<sup>2</sup>, and Nancy Cummings<sup>3</sup>

<sup>1,2</sup> University of Central Florida and <sup>3</sup> Florida Southern College

*(Received May 28, 2008, accepted July 18, 2008)*

**Abstract.** There are no models in the current literature that offer a unified theory of all of the factors that define crew race strategy and race day performance. This paper proposes an 8-factor model of crew race performance and summarizes the related literature. The model suggests those factors that should be used to analyze and evaluate the performance of crews in actual races.

**Keywords:** crew race performance, race plan, rowing strategy, coxswain role, swing effect

## 1. Toward a Generalized Model of Crew Race Performance

Various researchers (including Zatsiorsky and Yakunin, 1991; Soper and Hume, 2004; and Atkinson, 2001) have developed biomechanical models to mathematically forecast boat speed as a function of the physics of racing cadence, force vectors, shifts in mass and momentum, and hydrodynamic resistance. Such models are useful to study the theoretical efficiency of energy usage, but ignore the human factors of the race competitors – including skill, level of exhaustion, and psychological motivations. Computerized biomechanical models are deterministic in that they do not consider the uncertainties of race scenarios, intended strategies, the qualitative aspects of race day performance, and the situational aspects of how crews respond to their race positioning.

To evaluate how crews actually perform on race day, an 8-factor overall model of crew race performance is proposed (Figure 1). Each of the eight model components is further classified into four macro-categories:

- **Base Capability** defines the raw talent of a crew and their capabilities in using their equipment. It includes the two factors for Human Talent (**H**) and Biomechanics (**B**).
- **Race Scenario** defines the circumstances a crew faces on race day. It includes the two factors for the crew's Physiology (**P**) and the Weather and Environment (**W**) on this particular day.
- **Performance Execution** is how well a crew actually performs relative to its base capability and the race scenario. It includes factors for the Quality of Execution (**Q**) and the effects of Race Psychology (**R**).
- **Decisions** made before and during a race also affect the race outcome. These include the coach's pre-race Strategy and Race Plan (**S**) and the coxswain's actual within-race application of Tactics and Contingencies (**T**).

Putting this all together, the performance of a crew in any given race is a function of the base capability of the crew when faced with a particular race scenario, combined with their performance execution of the decisions made before and during the race. This is a complete conceptual model of a crew's performance. Each of these factors interacts with each other on race day in a complex way. Due to uncertainties, the results of a future race cannot be predicted, yet the results of past races can be studied and evaluated. The number of splits or race observations per crew affects how precisely races can be studied and analyzed. Collegiate competitions are typically reported with only one overall race time observation per crew. World championships report four quarterly splits. Other data may be available from audio or video records that

<sup>1</sup> Jeffrey L. Cornett: Tel. (407) 330-1968. Director of Institutional Research, Valencia Community College. Department of Industrial Engineering and Management Systems, University of Central Florida. Former coxswain for Cornell University, Potomac Boat Club, and the 1971 US Pan-American Team. E-mail address: jeffreylcornett@aol.com.

<sup>2</sup> Pamela McCauley Bush: Tel. (407) 823-6092. Associate Professor, Department of Industrial Engineering and Management Systems, University of Central Florida. E-mail address: mcbush@mail.ucf.edu.

<sup>3</sup> Nancy H. Cummings: Tel. (863) 680-4265. Assistant Professor, Departments of Physical Education and Athletic Training Education, Florida Southern College. E-mail address: ncummings@flsouthern.edu.

provide more detailed data to interpret.

## Model of Crew Race Performance

$$\text{Time} = f_{\text{split} = 1-n} ( \text{H} + \text{B} + \text{P} + \text{W} + \text{Q} + \text{R} + \text{S} + \text{T} )$$

where n = 1, 2, 4, 8, 20, 40, 200, or 10,000

### Base Capability:

**H** = Human Talent

Anthropometrics, age, gender, health, talent and experience

**B** = Biomechanics

Equipment, ergonomics, mechanics, kinematics and rowing style

### Race Scenario:

**P** = Physiology

Training and fitness, race distance, fatigue, energy expenditure and pacing

**W** = Weather and Environment

Water, wind, temperature, turns, lane fairness, random interventions

### Performance Execution:

**Q** = Quality of Execution

Strategy execution, performance errors, steering, synchronization and swing theory

**R** = Race Psychology

Race importance, morale and character, motivation and effort, concentration and focus

### Decisions:

**S** = Strategy and Race Plan

**Coach:** Competitive assessment, goals and planned contingencies, rigging, pacing, drives

**T** = Tactics and Contingencies

**Coxswain:** Situation awareness, options and risk assessment, pacing, drives, communication

Fig. 1: An 8-Factor Overall Model of Crew Race Performance.

## 2. Base Capability: Human Talent (H)

The human talent of a crew is a function of anthropometrics, age, gender, health, talent and athletic experience. This base capability defines how fast a crew should be able to perform if well trained and conditioned to race. Talent and experience also define the reliability of how well the crew should perform on a consistent basis.

International rowing competitions are classified (US Rowing Referee Committee, 2008) according to boat type (number of rowers in the shell), gender, lightweight versus heavyweight (referred to as “openweight” for women’s competition), age, and experience level. The effect of size and gender on rowing performance is easily seen in championship race performance times.

Valery Kleshnev (Kleshnev, 2006) studied the results of World and Olympic championships from 1993 to 2004 according to the various boat classes. Kleshnev filtered out the best and worst times because they were presumed to have been significantly affected by weather conditions. Comparing the percentage difference in the average winning times, the expected variations by gender (M vs. W) and by weight class (L for Lightweight) can be calculated. For the 5 classes of Olympic events common to both genders, the average winning time for women averages 10.2% greater than for men. For the 3 classes of lightweight events, their winning times average 2.6% greater than their heavyweight (or openweight) counterparts.

Percent body fat is another differentiator between men versus women. Volker Nolte (Nolte, 2005) offers a guideline for elite competitors that men’s body fat should not exceed 8 percent whereas women’s should not exceed 14 percent. The combination of height, weight and body fat percentage substantially define body cell mass (muscles, brain, and inner organs) – about 52 percent for elite male heavyweights. Of this, 85 percent is muscle mass, and 75 percent of this muscle mass is used in rowing. Because body cell mass is determined by body growth and training, younger competitors are at a disadvantage – until about age 19.

Performance differences by gender and size has also been studied through ergometer experiments (Yoshiga and Higuchi, 2003). Using multiple regression, rowing performance is shown to correlate with height, body mass, fat-free mass, and VO<sub>2</sub>max. Male rowers outperformed female rowers, but the expected variation by gender was reduced to only about 4% when adjusting for differences in size and aerobic capacity. Other factors to explain performance differences by gender include haemoglobin concentration, testosterone levels, and the relative size of leg muscles.

Besides anthropometric and physiological advantages, differences in human talent can also be attributed to rowing capacity and skill factors (Smith and Spinks, 1995). Discriminant function analysis was performed

on ergometer results comparing novice, good, and national level rowers. The most powerful predictor was propulsive power per kilogram of body mass. Other significant predictors included the skill factors of stroke-to-stroke consistency, and stroke smoothness. Because power and skill levels can be correlated with experience categories, having experienced rowers improves the reliability of a crew to perform consistently well.

In an overall model of crew race performance, the quality of execution is treated as a separate factor in determining how well a given crew performs in any given race. Nevertheless, size, gender and other anthropometric advantages provide an expected base line of crew performance. These anthropometric advantages can also be factors of intimidation that can affect race psychology and race plan strategy.

### **3. Base Capability: Biomechanics (B)**

The base capability of a crew is also a function of rowing technique and how well the crew uses and interacts with its equipment. In recent decades, the sport of rowing has been extensively studied using biomechanical techniques driven largely by new instrumentation technology and a growing interest in sports biomechanics. As described by Volker Nolte (Nolte, 1991), biomechanics is interested in how the rower converts physiological capacity into moving the boat. Biomechanical considerations include ergonomics, kinematics and rowing style. Superior equipment can also be a contributing factor in winning a race. Crews respond well and perform better when they use better equipment, have it optimally rigged to fit them well, and are well trained in how to use their equipment.

#### **3.1. Ergonomics and Equipment**

Ever since the sport of crew originated in the 19th century, the designs of equipment manufacturers have continually evolved to better accommodate the ergonomics of rowing, to maximize the mechanical advantages of equipment designs, and minimize the hydrodynamic drag from the shell and oars impacting the water.

One of the first major innovations was the introduction of the sliding seat between 1857 and 1861. The sliding seat allows the legs to be used as the primary form of propulsion. The timing of force application by the legs, arms and trunk, along with the dynamics associated with shifts in mass-momentum, results in a distinct profile of shell speed and the associated forces over the duration of the stroke (Jones and Miller, 2002).

Racing shells have been adapted in hull geometry design (Tuck and Lazauskas, 1996) to better fit the varying sizes of crews, water displacement and the associated hydrodynamics. Water resistance can be categorized into hull, pitch and skin resistance (Soper and Hume, 2004). Skin friction represents 88% of the water resistance to boat propulsion.

Oar blades have been redesigned to better catch the water, improve the quality of rowing bladework, and minimize negative hydrodynamic effects. In 1991, the asymmetrical "hatchet" blade was introduced. Some of the reported benefits of the hatchet blade (Soper and Hume, 2004) include more stability with less vertical movement, greater peak compressive force at the catch, and less slippage of the blade at the catch.

Outriggers have become increasingly adjustable to allow them to be individually adapted to fit each rower and accommodate diverse rowing styles including the quality of an individual's bladework. Rigging can be adjusted to raise or lower the oar blade relative to the water, thus better adapting to the wave height on race day. Rigging that is well-adapted to the rower's anthropometrics improves performance (Barrett and Manning, 2004). Rigging adjustments also allow the mechanical loads or "gearing" to be adapted to the expected race duration (affected by weather conditions), race strategy and stroke rate pacing.

#### **3.2. Kinematics of the Rowing Stroke**

The rowing stroke can be defined in terms of four phases (catch, drive, finish, and recovery) in which different muscle actions are activated in a coordinated sequence (Mazzone, 1988). The drive phase is a sequence where the emphasis is on legs, body swing, and arm pull-through.

Rowing style affects the performance of a crew. Crews vary considerably in the kinematics of rowing style according to the beliefs of their coaches and the difficulty of training rowers to conform to a common style. Nevertheless, a review of the rowing biomechanics literature (Soper and Hume, 2004) revealed evidence to support several commonly held beliefs:

- Higher stroke rates and longer drive lengths result in greater average boat velocity. However, it is difficult to do both simultaneously, so crews must fundamentally choose between these two in their rowing and racing style.
- Drive to recovery ratios are strongly negatively correlated to stroke rate and average boat velocity. Therefore, increases in stroke rate and velocity are primarily associated with speeding up the recovery phase of the stroke.
- Rowers of different ability levels can be distinguished by elements of both power and skill – including power per kilogram of body mass, propulsive work consistency, stroke to stroke consistency, and stroke smoothness.
- As stroke rate increases, peak oar force occurs earlier in the drive phase. The ability to maintain peak oar force through the middle of the stroke may also be an indicator of performance level.
- Greater force on the oar handle is generated when the elbows are extended at the start of the drive, and also when the elbows are kept close to the trunk at the finish.
- A sequence of power using first the lower limbs, then the trunk, and finally the arms may be a more effective rowing stroke for achieving greater boat velocity.

Aside from applying force to the oar, a rower also must move his own bodyweight horizontally and vertically during a stroke. Only 75% of the power is used to pull the oar (Nolte, 1991), whereas 9% is used to support horizontal body movement and 16% is used for vertical body movement.

### **3.3. Timing of Force Application**

The shape of the force power curve over the duration of a stroke has been widely studied. Jones and Miller (2002) found that rowers display individual or signature stroke profiles in terms of the shape of their force power curve over the duration of their stroke. Such individual stroke profiles are used to provide a basis for distinguishing the features of the stroke and classifying individuals.

The timing of force application during a stroke can vary according to coaching philosophy. Some biomechanical principles favor prompt application of power starting with a quick catch and a steep rise to maximum power early in the stroke (Schwanitz, 1991). His empirical research on boat speed compared to rowing style supports increased power emphasis on the early part of the drive. The position of the body in the early part of the drive is similar to that of a weightlifter at the beginning of a lift. Schwanitz interprets this position as allowing for a more synchronous whole-body effort incorporating leg, back and arm muscles. Emphasis on power at the middle or end of the drive would emphasize more isolated and smaller muscles. Early application of power also means that the force being applied with the oar is not at its most productive angle given the distribution of force along the two vectors of the horizontal plane.

Consideration of hydrodynamic drag and the associated benefits of maintaining a steady boat speed suggest that rapid force development at the catch and longer stroke maintenance at the finish should be emphasized instead of applying the highest peak force in the middle of the drive (Kleshnev, 1999).

On the other hand, a comparison of propulsive versus transverse forces on the oar suggests that force application is most inefficient at the catch and finish (Sanderson and Martindale, 1986). Even if you assume that exploding at the catch with power is a more effective technique for short rowing pieces, producing very steep force-time curves may be very costly in terms of lactic acid accumulation and energy production (Seiler, 1997). Therefore, sustaining this technique over the duration of a 2000-meter piece may not be a sound strategy if one wishes to conserve and pace the usage of the rower's limited aerobic physiological resources.

Coaching philosophies and biomechanical principles differ as to rowing style. However, it is generally regarded that more experienced crews will row more skillfully and therefore more efficiently and effectively. It is also generally understood that having the best equipment and having it skillfully rigged provides a competitive advantage. The advantages of experience, skill and equipment can often offset the size advantages of larger, stronger crews. Indirectly, even just a crew's beliefs about rowing style and the relative skill of their competitors can affect race strategy and the psychology of the race. The combination of human talent, equipment and skill-based biomechanical advantages defines the "base capability" for a crew.

## **4. Race Scenario: Physiology (P)**

The race scenario is an important factor in race strategy. A well conditioned crew should bring with it

the training, conditioning, and physiological capability needed to compete well, given its race strategy for the given race scenario. However, excellent human talent, rowing technique and proper equipment are not enough. The crew must also be fit and well conditioned for the race distance it is rowing. The crew must balance and spend its energy reserves over the duration of the race. This involves pacing the stroke rate and level of energy expenditure to match the gearing of the crew's rigging so that the crew's energy "budget" is used optimally over the 2000 meters.

From a physiological standpoint, the competitive goal is to find ways to deliver the most oxygen to muscles as fast as possible while balancing the pace of energy usage over the duration of the race. For short periods, muscles can work without oxygen through anaerobic respiration. For longer periods, oxygen is needed to sustain aerobic energy (along with the consumption of either glucose or fat). About 85% of the energy requirement during a crew race is supplied aerobically (Seiler, 2005), while the remainder is supplied via anaerobic pathways. Other research (Maestu, 2004) has yielded varying estimates, but the most recent research places the aerobic component around 85%.

The exact estimate of the aerobic/anaerobic mix may not be as important as how to apply this knowledge in developing race strategy. Coaches disagree on the ideal steady-state stroke rate and energy usage levels to adopt during the middle of a race. They also disagree on the desirability and frequency of use of big-10's during the body of the race in order to make planned "moves" on other crews at key psychological points during the race. Although such moves may provide psychological advantages to crews as they strive to implement their race plans, these extra energy expenditures may just be borrowing from energy reserves otherwise rationed for use later in the race.

The concept of a maximal lactate steady state (MLSS) has been studied (Billat et al, 2003) as a bridge between biochemistry, physiology and sport science. MLSS is the highest point in the lactate turnover equilibrium – the point at which lactate appearance and disappearance are balanced. MLSS provides a basis for understanding the energy pacing possible in a 6 minute crew race, as well as the means and consequences of varying the pacing of energy usage throughout a race. For trained athletes, Billat estimates endurance time at MLSS to last about an hour. Crew races which average around 6 minutes are much shorter in duration. Therefore, the average energy pacing of a crew race is above the steady-state MLSS workload, and lactate levels should peak at the maximum possible level at the end of the race. Consequently, crew races are often referred to as 2000-meter "sprints" even though the high consumption of aerobic energy reveal crew races to also be an endurance sport.

The physiological science and the strategy behind a 2000-meter crew race is not simply about maintaining a steady-state effort, but rather about how much above the steady-state MLSS a crew should expend its energy, the timing of when to exceed this threshold, and whether deviating the pacing above the level of MLSS is somehow strategically or tactically warranted. The extra energy expended to support a big-10 or other tactical drives accelerates the timing of energy usage, but is not the sole rationale for a crew to row above the MLSS equilibrium. Somehow, the crew needs to burn its energy above this equilibrium so that all of its anaerobic energy is consumed.

The physiological means of obtaining the extra energy for a big-10 or similar drive may be enhanced by the "fight-or-flight" enzyme – glycogen phosphorylase. Glycogen reserves are a factor in exhaustion at MLSS (Billat et al, 2003), and glycolysis can be mediated by adrenogenic activity. Therefore, it is possible that the motivational psychology of calling a big-10 could lead to a fight-or-flight mental state triggering enzymes or adrenaline that would lead to a temporary burst in energy and resultant boat speed. This would explain why big-10 style moves could provide a temporary burst in speed when the rowers are already thinking they are rowing at full power and are already burning their energy at a rate above the relative comfort level of the MLSS steady state.

The eventual consequence of exercising above the steady-state critical power and beyond the endurance limit for this level of power is exhaustion. Continued exercise after exhaustion is only possible by reducing work rate and the corresponding power output to a level below the critical power (Coats et al, 2003). This work rate after exhaustion is reduced to a level that relies predominantly on aerobic energy transfer, and in so doing, allows exercise to be sustained.

In terms of racing strategy, a crew can race significantly above its level of critical power for only a limited duration. After achieving exhaustion, the crew is burnt out and will continue to row only at a sub-optimal level of power. Therefore, one of the keys to race strategy is to time the level of intensity and duration of power to achieve exhaustion near the end of the race. Otherwise, the loss of power and speed

after exhaustion may offset the gain from rowing earlier in the race at a work rate above the critical power.

The amount of energy available above the level of critical power can be thought of as a constant and finite level of energy store (Fukuba et al, 2003). This is comprised of a phosphagen pool, an anaerobic glycolytic component, and an oxygen store. This pool of energy is modeled as a hyperbolic curve that is a function of power versus duration, and is considered to be the equivalent of the oxygen deficit or the subject's anaerobic work capacity. This work capacity in excess of critical power can be utilized rapidly by exercising at a higher work rate, or may be sustained for longer durations by exercising at lower work rates. Research (Fukuba et al, 2003) also suggests that this excess work capacity is a fixed amount and not affected by the pattern of power variations – at least for power ranges in cycle ergometry from 100 to 134% of critical power. From the standpoint of race strategy, this supports the notion that crews could strategically vary their level of energy consumption during a race, and in a wide range of patterns, up until the point where their anaerobic energy store is cumulatively consumed and exhaustion sets in. What is also suggested by this research is that no part of the race should be rowed below the level of critical power if an optimal time is to be achieved.

## **5. Race Scenario: Weather and Environment (W)**

Weather and environmental conditions are important aspects of the race day scenario. Unpredictable factors such as wave height can affect the ability of a crew to row well (including minimal splashing and a clean catch and finish). Headwinds and tailwinds or currents in the water also determine the effective distance of the race in terms of expected time and total strokes. A head wind slows the race. A tailwind speeds up the race. Other environmental influences affecting crew comfort level and expected race speed include temperature (air and water), water depth, water density, altitude, and air pollution.

Not all conditions affect each crew fairly. Some lanes may have advantages. Random events can occur including obstacles in the water or wakes from other boats on a lake or river. Even though courses are laid out to offset the curvature advantages of inside lanes, it is inevitable that turns in the course can affect perceived race positioning and therefore race psychology.

The referee handbook specifying the Rules of Rowing (US Rowing Referee Committee, 2008) specifies factors that must be considered before a race course is judged suitable for a registered regatta, including whether the course is uniformly sheltered from the wind, whether the course is free of any current, and whether any current that does exist is slight and equal across the course.

In recent years, all world rowing championships are raced on straight and narrow channels usually custom built for crew racing. Water current, water depth, and the random effects of other environmental factors are minimized. However, until the day that the first crew race is held on an indoor course, the effects of wind direction and speed are still uncontrollable factors that can shorten or lengthen race duration, and can have unfair effects on racing lanes.

Statistical regressions on winning times over 14 years (Kleshnev, 2006) reveals a gradual pattern of improving times in 13 out of 14 boat classes (women's double sculls being the exception). Nevertheless, fluctuations in winning times are substantial and important in terms of race strategy. Winning times for both men's and women's 8's competition can vary by 40 seconds or more from year to year. This is certainly due to environmental conditions – not due to the quality of crews varying this much each year.

Wind and weather can vary dramatically within a short period of time – sometimes just a matter of minutes. This is a critical aspect of the race scenario for which crews need to be prepared. Part of the challenge of each coach is to anticipate the rowing conditions their crews will actually face at race time. The gearing of the rigging and oars can be adjusted to affect the leverage and level of energy needed per stroke for a given stroke rate. A crew can be prepared (gearing, stroke rate plan, and expected pace of energy expenditure) for a race expected to last 6 minutes and yet experience race conditions that can be as much as 40 seconds faster or slower.

## **6. Performance Execution: Quality of Execution (Q)**

One can define "performance" simply in terms of how well a crew placed in the race. Thus, winning is the best performance possible, and losing means their performance was the worst possible. Consider this to be the performance result.

For purposes of a crew race performance model, "performance execution" is defined based on the combination of the quality of execution (Q) of a crew and the effects of race psychology (R). A losing crew

could still have rowed very well, and perhaps even better than was expected from them. A winning crew could have performed poorly in terms of their effort and execution, but still easily win a race due to the weakness of their competition. A crew's quality of execution is determined not simply by winning or losing, but whether the crew executed according to its potential.

The quality of execution of a race can be judged in three ways:

- **Strategic Execution** – whether the crew adhered to its race plan, and whether the race plan was the best choice for the race scenario.
- **Technical Execution** – whether the crew rowed mistake-free in terms of blade work, steering, and other imperfections or misfortunes.
- **Teamwork and Synchronization** – whether the crew rowed in a coordinated manner, the rowers' styles blending well together, and possibly even achieving a “swing” effect.

### 6.1. Strategic Execution

A race plan is the combination of strategy and tactics planned for a race. The plan is established by the coach but needs to be implemented by the crew. The coxswain may need to react to unexpected race circumstances, and make appropriate tactical adjustments based on the contingencies for which the coxswain has been trained. If a crew executes the coach's strategy as planned and if the crew responds appropriately in terms of tactical contingencies, it has performed well in terms of strategic execution.

Although a crew can follow its race strategy and tactics perfectly – making all the moves and stroke rate changes exactly as planned – the crew may still fail to perform as well as expected relative to the competition. This does not necessarily mean that the crew failed in terms of strategic execution. Poor strategic execution is when a crew unintentionally deviates from its strategy and tactics. A failure to execute race tactics properly could include settling too high or too low off of the racing start. It could also include timing errors on the part of the coxswain, such as accidentally changing stroke rates at the wrong time during a race. The consequence of the coxswain calling a sprint much sooner than planned could be that the crew becomes totally exhausted before the race ends -- thus resulting in suboptimal physiological performance.

Coaches sometimes allow a coxswain tactical discretion as to whether to call up the stroke rate at the end of a race earlier or later than planned, or not at all if the crew seems safely in the lead. If such contingent tactical choices fail to achieve the desired effect, this can also be viewed as a failure in race strategy execution.

Sometimes, the coach has chosen the wrong race plan for the crew given the race scenario that day. A strong head wind could make the race last much longer than originally planned. A tail wind can have the opposite effect. The coach has geared the rigging of the crew and chosen a race plan based on a set of assumptions about the race conditions. Should the actual race conditions be different than planned, the crew or coxswain might or might not choose to deviate from their race plan. Regardless of the cause, executing the wrong strategy and tactics for the specific race day scenario can be viewed as a failure in strategic execution.

### 6.2. Technical Execution

Many things can go wrong that are the result of technical errors on the part of the rowers or the coxswain. At elite levels of international competition, no major errors are expected, yet even minor errors could still produce the difference between winning and losing in a very close race.

Technical errors in rowing style can be subtle and difficult to perceive by race observers, but still affect the feel of the boat. This includes sloppy blade work, imperfect timing and synchronization, and a boat that is not well balanced (occasional tilting toward the port or starboard side).

Major technical errors can have more dramatic consequences for a crew, but seldom occur in elite competition. These can include catching a full or partial “crab” (when the rower's oar gets stuck in the water at the finish of a stroke), collisions with course obstacles, interference with another crew, jumping the start, broken equipment, and injuries to rowers. Misfortunes can dramatically affect crew performance and race times. Some rules infractions can even result in the crew being disqualified from the race.

### 6.3. Teamwork and Synchronization

Synchronization of the various elements of the rowing stroke and the timing of force application has been studied among rowers to explore the potential advantages and even the disadvantages of each rower

being perfectly in synch with each other. Most coaches agree that good synchronization is highly desirable.

Research suggests that successful rowing performance is influenced by the consistency of intra-stroke fluctuations in boat velocity and that wider fluctuations are associated with less successful technique (Soper and Hume, 2004). Fluctuations in boat speed occur throughout each intra-stroke phase of the rowing cycle. As stroke rates increase, intra-stroke fluctuations in boat velocity significantly increase. The fluctuations tend to be asymmetrical around the average boat speed with greater reductions in boat velocity than the increases. The non-linear relationship between hydrodynamic drag and boat speed causes stroke-rate fluctuations to be sub-optimal in terms of the energy expenditures needed.

Kleshnev (1999) studied blade efficiency and hydrodynamic drag effects as a function of stroke rate and the timing of power during a stroke. He found that increasing stroke rates led to an increase in velocity variation and therefore a measurable loss of efficiency.

One of the most widely cited studies on rowing coordination and consistency is by Wing and Woodburn (1995). They defined three important components to crew coordination: having a common periodicity (cycle of activity), good synchronization (correspondence of phase), and similar force-time profiles. Wing and Woodburn illustrated how crew exhaustion affects the force-time curve. The Wing and Woodburn study examined the similarity of rowing styles among the crew and how consistently the rowers maintained these styles over time. They offered the interpretation that greater synchronization results in less wasted effort. The wasted effort is due to the inefficiencies of turning moments associated with poorly synchronized strokes and the unequal forces produced by each rower.

#### **6.4. The "Swing" Effect**

According to the US Rowing web site (US Rowing Nomenclature, 2008), "Swing is a hard-to-define feeling when near-perfect synchronization of movement occurs in a shell, enhancing the performance and speed of the crew." This effect is rarely achieved even amongst the best of crews. The concept of swing is controversial in that not all coaches and crews even believe in this effect. Instead, they attribute such unexpected speed to simply exceptional effort (or psychological affect). Although nobody has yet provided a scientific explanation for swing, the rowing literature contains many references to swing as an unusual performance enhancing experience that is generally associated with good synchronization among the crew.

For purposes of elite crews competing at the world championship level, it remains a matter of speculation as to how often elite crews ever experience a dramatic swing effect, or whether they routinely experience it and just don't notice it as anything unusual. However, there are personal accounts of unusually good performances. For example, Lesley Thompson-Willie (Thompson-Willie, 2005) described her experience as a Canadian national team coxswain winning a gold medal at the 1992 Olympics. She describes rhythm and ratio (time on the slide compared to time with the blade in the water), the feel of the shell, and how the "boat will have a certain glide beneath you that is hard to describe." She says there are only a few times that she has ever felt this in a race, but that the 1992 Olympic final was one race where "everything felt perfect."

### **7. Performance Execution: Race Psychology (R)**

Simply rowing a good, technical race does not mean the crew performed to its potential. The quality of a crew's performance relative to its potential can be evaluated in terms of their psychological commitment to the race and their ability to focus on producing their best effort. The crew's effort and commitment to the race is a function of the psychology of their competitive positioning as the race progresses. The ability of a crew to make their best effort is also a function of how well the athletes focus on what they need to be doing and not be distracted by counterproductive thoughts.

#### **7.1. Motivation and Effort**

The effort a crew puts into a race is a function of how close the race is and whether the rowers are motivated to make the effort they are capable of exerting. Sometimes, holding back in a race is appropriate – such as when a crew is conserving energy for a future race. Sometimes, when winning a race, a crew may delay or withhold its sprint because it is unnecessary and increases the risk of technical errors or exhaustion. Influences on motivation and effort include race importance, perceived conditions in a race, the morale and character of the crew, and race psychology.

If race psychology does not influence the dynamic performance of a crew, then every race might as well just be a time trial with crews rowing in isolation! Each crew would just execute its ideal race plan for



today's race scenario. Theoretically, a crew should know the ideal race plan to minimize its time over a 2000-meter race distance. Psychology is believed to contribute to both the level of effort and quality of effort needed to achieve a superior performance.

Klavora (1980) discusses the psychological basis of racing and compares the advantages and disadvantages of the "even-paced" racing strategy to the "early-lead" racing strategy. Rowing is the only sport where the athletes do not face the forward direction (except for the coxswain). The lead crew is in an authoritative position since the rowers can observe their trailing opponents and can react to their tactical intentions. They can counteract an opponent's attack so as to hold onto the lead. According to Klavora, "In these instances "extra" energies which, in normal circumstances, are not available to competing athletes, are mobilized in the oarsmen of the leading crew."

Compare this to the even-paced strategy where a crew must row from behind in the race. Even pacing is the most economical way to row a race from a physiological standpoint. However, according to Klavora, it generates substantial psychological disadvantages. Not being able to see what is going on in the race, the rowers cannot directly judge who is leading the race, the distance they are lagging, and whether they are still within striking distance. Although the coxswain's job is to inform the crew, "hearing does not mean believing." Rowers are tempted to look around and peek over their shoulders – which can lead to disturbing the crew's rhythm and balance.

According to Klavora, there are few rowers with a "strong enough personality to take the beating of rowing in the tail in the early phases of a race." However, by rowing more economically, they may be able to overtake their opponents in the second half of the race. Overtaking opponents one by one can be "psychologically devastating for the tiring opposition, who are desperately trying to hold onto their lead."

Jennifer Johnson (1989) wrote about the psychology of pushing through the pain: "When the legs are screaming at the rower to stop ... how does he keep going?" She defines the purpose of sports psychology as to "help the athlete push beyond the limitations imposed by the rational mind." She cites the example of Kris Karlson, 1988 world women's lightweight sculling champion, who said that when she reaches the point where she feels she cannot go on, she often notices that she is moving on other people. "Wow! They are dying more than I am." She starts "getting psyched" and manages to block out how dead she is and starts to focus on how she is winning. Johnson's experience illustrates how crew races can truly be psychological competitions.

## 7.2. Concentration and Focus

Baltzell and Sedgwick (2000) interviewed elite level rowers and their strategies toward optimizing performance through their ability to cope with competitive pressure before and during the competition. They developed a "coping-excellence model of elite rowing" that blends intrinsic and extrinsic motivation along with habits of excellence. Extrinsic motivation is the desire to achieve external success – such as earning a place on a team, winning races or medals, and receiving the coach's praise. Intrinsic motivation is the innate desire to perform well and be in control while working toward their goal – such as to improve fitness, rowing technique, and rhythm. The habit of excellence reflects the principle that rowers race the way that they practice. Figure 2 summarizes the coping scenarios most commonly suggested by those elite rowers who were interviewed.

This research emphasized the importance of having a race plan and focusing the rowers' mindset on what they can control including rowing efficiently, keeping relaxed and rowing with good rhythm. Pulling hard is necessary but most effective when it was a previously habituated response. Before the race, attention should be on the race plan which can be supplemented using mental skills such as imagery and goal setting. Baltzell and Sedgwick concluded that rowers need to be highly motivated to optimize their speed and performance, need to build habits of excellence into their daily practice, and that personal enjoyment and intrinsic motivation are more effective when coping with high levels of competitive pressure.

Most effective coping scenarios	Least effective coping scenarios
<b>Before the race:</b> <ul style="list-style-type: none"> <li>• Adopt a “just do it” mindset.</li> <li>• Interpret pressure as a positive challenge.</li> <li>• Rehearse, think through, and discuss the race plan.</li> </ul>	<b>Before the race:</b> <ul style="list-style-type: none"> <li>• High expectations and excessive focus on the outcome.</li> <li>• Ineffective preparation mentally, physically, and having no race plan.</li> <li>• Negative thoughts dreading the race and feeling out of control.</li> </ul>
<b>During the race:</b> <ul style="list-style-type: none"> <li>• Technical-physical efficiency including conserving energy, finding good rhythm, and focusing on technique.</li> <li>• Focus on the process of rowing rather than the race outcome.</li> </ul>	<b>During the race:</b> <ul style="list-style-type: none"> <li>• Lack of control and feeling powerless over their ability to change how they are rowing and the speed generated.</li> <li>• Resignation and mentally giving up on winning the race.</li> </ul>

Fig.2: Recommendations for Coping with Competitive Pressure (Baltzell and Sedgwick, 2000).

Research in other sports examines other ways that athletes experience psychological stress. Bar-Eli et al (1992) investigated how high levels of arousal can lead to anxiety that negatively affects tennis player performance. They defined a “psychological performance crisis” as when an athlete has difficulties performing a task in competition due to extreme physical and psychological arousal. They were able to correlate impaired motor performance with high levels of stress.

Tate et al (2006) studied techniques for modelling the relationship between athletic performance and levels of psychological affect (i.e. arousal). They proposed that there is an optimal range of affect within which an individual athlete’s performance is enhanced. They termed this the “Individual Zone of Optimal Functioning (IZOF)” and likened it to how athletes will sometimes characterize themselves as being “in the zone” when competing. Being too high or too low on the affect scale can lead to suboptimal or even dysfunctional performance.

The need to achieve a balance in the optimal amount of motivation and the need to focus on the most effective types of motivators has led many authors to research and propose how to train athletes psychologically. Waitley et al (1983) described how the Eastern Europeans were the first to employ sports psychologists on the staffs of their national teams. They state the goal of sports psychology is to “optimize competence through the development of psychological skills that will permit athletes to enhance performance and gain maximal satisfaction.” To address the need for balance, they recommended a variety of stress reduction techniques that could be taught to athletes by sports psychologists, including active rest, deep muscle relaxation, biofeedback, and assertiveness training. Assertiveness training means being “brain-controlled” rather than “emotion-controlled.” Consequently, they advocate training techniques in imagery training, cognitive reconstruction, and mental rehearsal.

According to Horsley (1989), asking rowers to “concentrate” is too vague. To improve their concentration, they must be given specific information and taught to work on specific skills – both mental and physical. The attentional demands of rowing are constrained by the brain’s limited capacity for processing short term memory, and by individual attentional style narrowly focusing on internal or external sources. Internal focus when racing includes awareness of lactate build-up, muscle tension, breathing control, task-related thoughts, and awareness of rowing technique. External focus when racing includes awareness of the coxswain, his/her instructions, race officials, the boat and water, teammates, other crews, and other coxswains. Problems occur when rowers become overly distracted with external cues or become overloaded with internal cues (perhaps due to anxiety). Horsley advocates that rowers need to practice calming their minds and develop strategies to focus on appropriate cues. He suggests using both off-water and on-water concentration drills.

During unsuccessful performances, athletes may have programmed their own failure through self-doubt and negative statements. They are looking for an excuse for their potential poor performance telling themselves they don’t row well in a cross wind, the rigging is wrong, or they ate the wrong food. To overcome this self-doubt, Johnson (1989) recommends techniques of self-talk, countering, thought stopping,

and visualization.

Nideffer (1981) is another advocate of attentional control training in sports psychology. He recommends a technique that focuses concentration on the internal center of gravity of the body. He asserts that the average individual can be taught to control the inter-relationship between thought processes, centering attention, and physiological arousal.

Butler et al (1993) advocate “performance profiling” as a means of facilitating an understanding of the way an athlete perceives his/her ability and preparation for performance. Although the sport they studied was boxing, performance profiling addresses what they consider two fundamental aspects of applied sport psychology: self-awareness and goal setting.

Joy (2005) advocates a scheduled yearly mental training cycle to include five meditative training techniques: quiet sitting, visualization, relaxation, concentration, and mindfulness. Joy believes these meditative practices should be practiced both on land and on the water beginning with the first practice, and that this training leads to “flow” (analogous to swing) and peak performance. According to Joy, “Mental training enhances the flow and power of physical movement by allowing efficient release of energy.” It involves “a total integration of body movements with the shell, blades, and water, along with a heightened awareness and concentration.”

Joy witnessed the power of this technique in 1984 as practiced by coach Neil Campbell with the Canadian men’s eight in winning the Olympic gold medal. He attributed their oneness of body, mind and spirit to allow these rowers to relax, focus, and enjoy the competitive moment.

## **8. Decisions: Strategy and Race Plan (S)**

A student once asked, “What is there to learn about rowing strategy other than to just pull hard?” To an untrained eye, there would appear to be no strategy at all to a 2000-meter sprint. The coach trains the crew to begin with a racing start, lower its stroke rate to a sustainable rate in the middle 1000 meters, and then sprint at the end of the race. If the crew pulls as hard as it can and executes its coach’s stroke rate pacing plan, the crew should finish in its optimum race time. Theoretically, it is just that simple.

### **8.1. Coaching Philosophies**

US national team coach Mike Teti is an expert on racing strategy having coached the US men’s eight to the Olympic gold in 2004 (the first US gold in the eight since 1964) and then repeating as the world champion in 2005. According to Teti and Nolte (2005), strategy is a skillful plan to reach a goal, and tactics are the means to implement the strategy. They believe a coach needs to use any information available about their competitors in order to create a winning strategy. A coach also must consider many other factors including the importance of the race, the level of competition, and even weather.

However, they consider the most important factor in choosing a race strategy is to adapt the race plan to your athletes and to set realistic goals. When adapting your strategy to your crew and setting realistic goals, Teti and Nolte assert, “Winning a bronze is much better than racing for victory and coming in fourth.”

In training for competition, the crew should already have figured out the crew’s most effective stroke rate. According to Teti and Nolte (2005), the adrenaline that comes with a major race may cause the crew to row higher than planned. If the crew is within one stroke per minute of plan, they believe no adjustment is needed. If off by more than that, an experienced coxswain should then make an adjustment.

Teti and Nolte (2005) believe that a race plan should reflect not only technical and physiological capabilities, but also psychological strategy. Rowers often say their most memorable race is when they rowed an even pace at the beginning of the race and then rowed through the competition to win at the end. Nevertheless, Teti and Nolte believe in the racing philosophy of a fast start and trying to take the lead early. They advise that you always need to stay with the leaders because it is difficult to get big margins back. They also suggest that a crew that gains a one-length lead by the 1000-meter mark can “get brave” knowing they only have to hang on to their lead for another 2 minutes and 38 seconds.

Racing information on your opponents is available in terms of official results and 500-meter splits. Stroke rates can be taken from the shore. Teti and Nolte (2005) believe, “You have to interpret and use this information to the best of your ability.” Split times give coaches an idea of competitor speed distribution throughout the race. Because other coaches also study race results, Teti and Nolte favor using different race profiles in the heats and the finals so as to throw off those competitors who are studying them.

## 8.2. Gearing and Pacing Strategy

Hydrodynamic resistance to the flow of the boat is a function of skin drag, form drag, wave drag, and forces resulting from poor technique (Jones and Miller, 2002). The predominant source of resistance is skin friction with the water. The laws of fluid dynamics show this skin friction to be proportional to the velocity of the boat squared while the metabolic power consumed in moving the boat is related to the velocity of the boat cubed (Secher, 1993).

Consider an example by Nolte (1991) calculating the water resistance effects of maintaining a constant velocity of 5 meters per second compared to a speed distribution that spends half the time at 4 meters per second and the other half at 6 meters per second. Although both of these scenarios average 5 meters per second, the latter results in 4% greater boat resistance.

Thus, the metabolic cost to the rower is minimized by maintaining a constant boat speed. This would encourage race strategies that maintain a constant speed over the course of a race while minimizing or eliminating racing starts and sprints. Greater hydrodynamic resistance could also argue against the use of big-10 drives due to the extra energy needed to increase velocity while making a temporary drive in the body of the race.

Mechanical gearing is part of the overall race strategy as planned by the coach. For longer races or for races to be rowed at higher stroke rates, the gearing leverage can be lightened to reduce the work per stroke and thus balance the physiological energy expended according to the capabilities of the rowers, the expected time duration of the race, and the planned total number of strokes.

In spite of the non-linear effects of hydrodynamic drag, the goal of crew racing is to row at the fastest overall average speed so as to achieve the fastest time possible. Effectively using all of the available anaerobic and aerobic energy resources argues against using a constant speed throughout a race. Furthermore, the race plan must factor in the psychological advantages of leading in a race or staying within striking distance of the leader.

## 8.3. Strategy Profiles

Klavora (1979) defines the basic principle of the even-pace strategy is to start at the highest stroke rate that can be sustained throughout the race so that the last remnants of energy to reach the maximum possible oxygen debt is used up in the last stroke of the race. The crew would begin with a moderately fast start, quickly settle into an optimal racing rhythm, and would not sprint at the end of the race.

According to Klavora, although an even-pace strategy has been proven by physiologists to be the most economical, it is very hard to achieve in actual practice. He cites examples of world championship crews that demonstrated an even-pace strategy. The even-pace strategy was demonstrated based on their official 500-meter split times. However, his data do not show whether the crews actually took a racing start or a finishing sprint. Nevertheless, he concludes that, "it is obvious that whenever even pacing has been followed it has brought success to crews employing this racing plan at an elite level of competition across a variety of events." He goes on to explain that the even pace strategy may work better at the highest level of competition because such crews know their physical capabilities perfectly, and it takes years of experience to learn to row at a consistently even pace.

Pacing studies have been published (Garland, 2005) that examine how average stroke rates and speeds vary among the four 500-meter quartiles of race. However, these patterns do not isolate the pacing and speed effects of racing starts and final sprints (roughly 250 meters each) since these are blended into the results of the 500-meter segments.

Another study (Kleshnev, 2001) examined 12 "patterns of race strategy" defined as the quartiles where crews are at their fastest and at their slowest relative to the other crews, and the relationship of this fast-slow pairing to how well the crews finished in the race. For example, a 1-4 pattern means the crew performed its best relative to the other crews in the first 500 meters and performed its relative worst in the last 500 meters. This study shows no single best strategy and raises many unanswered questions about race dynamics, the effort sustained by losing crews, and the statistical validity of comparing times of winners against time averages that include crews that were hopelessly out of contention. Also hidden from this study are the timing and discrete effects of drives and counter-drives as crews execute tactical moves to gain or hold the lead.

## 9. Decisions: Tactics and Contingencies (T)

Strategy decisions are made by the coach before the race in the form of a race plan. The coach drills this race plan into the crew – possibly allowing for race contingencies. The coxswain serves as the “agent” of the coach in executing the race plan. Tactical decisions are made by the coxswain during the race – either closely following the race plan or making tactical adjustments on the fly depending on the contingencies the crew experiences during the race.

### 9.1. Responsibility for the Race Plan

Crews usually begin with a racing start for roughly 250 meters and then settle to row the body of the race at a lower stroke rate. Most crews will call up the stroke rate with about 500 meters to go, and finish with a full sprint over roughly the last 250 meters.

Yasmin Farooq is a former world champion coxswain for the US women’s eight. In Figure 3, she summarizes a typical race plan (Farooq, 1992) along with the goals she would communicate to her crew at each phase of the race.

#### First 500 meters:

- 5 strokes at stroke rate of 48 with a goal of building boat speed and lengthening to full slide.
- 30 strokes at 44 stressing rowing light, quick, efficient, and to breathe.
- 20 strokes at 40 while increasing spacing using body swing.
- 20 strokes at 38 while increasing spacing using leg drive.

#### Second 500 meters:

- The crew should be rowing at 37 strokes per minute.
- At some point, take a power 10 for “connection and explosiveness.”

#### Third 500 meters:

- At some point, take a power 15 for “horizontal swing” while shifting up the hull speed.

#### Final 500 meters:

- 20 strokes at 38 with a goal to build the energy with each shift, accelerate the boat, and keep length.
- 20 strokes at 40.
- 20 strokes at 42 with concentrating on matching body swing, sitting up but keeping full slide, and catches.

Fig.3: Sample Race Plan (Farooq, 1992).

Tactics may include big-10's or drives at one or more points in the race in order to try to make a move on the other crews. Drive tactics vary from coach to coach. Some do not use them – preferring that the crew row at a steady level of effort throughout the body of the race. Other coaches plan one or more drives lasting 10, 15, or 20 strokes each. Other crews plan to take drives at the discretion of the coxswain as circumstances seem to warrant -- often to achieve a psychological effect to inspire your own crew and to discourage your opponents.

### 9.2. Coxswain Duties

According to Farooq (1992), the coxswain has five primary duties:

1. Steering
2. Technical coaching (assisting the coach)
3. Help practices to flow smoothly
4. Motivating the crew and teamwork
5. Racing and strategy

According to MacDonald (1980), the coxswain’s job is to implement the race strategy that has been formulated by his coach. If the race does not go according to plan, the coxswain may have to formulate and alter strategy in the midst of a race. In this case, MacDonald compares the role of the coxswain to that of a quarterback calling an audible at the line of scrimmage.

When your own crew is moving on the competition, MacDonald cautions that the coxswain must describe that movement in a way that guarantees it will continue. He states that coxswains can actually destroy movement by getting the crew so excited that the rowers lose their sense of pacing and begin to rush.

When the other crew begins to move on you, MacDonald describes the coxswain's challenge as to prevent the crew from panicking and to find a solution to the internal problems that may be hurting performance. In any case, the coxswain should never lie to the crew or his/her credibility is lost forever.

Although the coach's race strategy is drilled into the crew, teams rarely practice adapting to unexpected deviations from strategy, such as how to adjust the stroke rate after settling at the wrong pace after the racing start. Likewise, unexpectedly trailing or unexpectedly leading in a race present new race scenarios for the coxswain to consider and for which the coxswain should be prepared to make adjustments. McArthur (2005) cites an example of one of his crews unexpectedly finding themselves in front of the rest of the field by a wide margin. It was such a shock to them that they did not know what to do, and so they never really settled into the race, and were overtaken by the other crews in the last 500 meters.

The judgment needed to deal with unplanned contingencies requires situation awareness, the courage to act independently, and the experience to know how to adjust race tactics and perhaps even adapt to an entirely new race strategy. The coxswain must know the available options and be able to assess the relative risks from deviations from plan. Tactics include adjusting stroke rate, taking big-10 drives, and communicating effectively to the crew to adapt to circumstances while keeping them motivated.

It was Farooq's experience that before each race, the crew would map out its race strategy. They would also plan a backup strategy in case the crew is not where it should be at a certain time. Everyone (coach, rowers and coxswain) knows the backup strategy before the race begins.

Farooq also advises that your arsenal of motivational and technical tactics should include only a few key points in the race where you want to make moves on the competition. Most moves are decided and discussed days or even weeks before the race between the coach and team. Together, the team discusses the technical focus for each move and sometimes the motivational focus. Rarely are more than two moves planned for a race, but that leaves the coxswain the flexibility for spontaneous moves on the competition.

Farooq describes one move they used in the 1990 world championships. They labeled this the "flex" as an abbreviation for flexing a little muscle. It was meant to be the best 10 strokes of their race and was used only once per race. It was also exercised only once each practice.

### **9.3. Tactical Race Decisions**

The amount of leeway and judgment permitted a coxswain varies based on the coach's philosophy. Coxswains may have discretion as to when to call up the stroke rate at the end of the race – earlier or later than planned, and perhaps not even take a sprint at all if it is not needed. These tactics are available to the coxswain to experiment with and adapt to race circumstances, or the coach could instruct the coxswain to blindly follow the preplanned race strategy.

A crew typically uses a racing start for the first 20 or 30 strokes (roughly 250 meters) before setting down to cruising speed and finishing with a sprint. This is evidenced by studying the splits of world championship competitions, including a recent study of the 2000 Olympics and 2001-2002 world championships (Garland, 2005). Compared to the average velocity over the 2000 meters, the quarterly splits show relative velocities of 103.3%, 99.0%, 98.3%, and 99.7%. The pattern of results from Garland's study show close consistency between the proportional time splits for men vs. women and for winning crews vs. losing crews.

Garland's study included all of the qualifying rounds as well as the finals competition. Because qualifying rounds were included, he chose to include only those race results where there was evidence that the crews made a good attempt to complete the course in the shortest possible time. The data suggested that 41% of all regatta races should be excluded due to abnormal race patterns.

He interpreted two reasons for needing to exclude these races: 1) the crews overestimated their ability and set off at a pace that was too fast to sustain, or 2) there was a "deliberate tactical decision" to slow down to conserve energy for further rounds of the competition. He could not tell how often each of these reasons occurred, but one can assume that any deliberate tactical decisions were made as contingencies during the race due to the crew being comfortably ahead or hopelessly behind. In many race circumstances, it makes sense for losing crews to save their energy for their next race, and for winning crews to conservatively just sit on their lead without taking a full sprint.

## **10. Putting the Model to Use**

The performance of a crew in any given race is a function of the base capability of the crew when faced

with a particular race scenario, combined with their performance execution of the decisions made before and during the race. The proposed 8-factor model of crew performance provides a conceptual framework for researching and interpreting crew race performance in terms of these eight separate factors.

This model can be put to use in analyzing and interpreting the results of historical race performances. Recommendations for applying this model include:

- **Data:** Gather detailed race performance data to use as a basis for performance analysis. Gather data from public and private sources (such as video race records) that go beyond the official race finish times and beyond the 500-meter splits reported for international races.
- **Analysis:** Use the tools of statistical analysis to assist in race analysis, but do not simply rely on computational results to interpret race performance. There are many confounding variables in a race, and the best statistical fit may not accurately portray what truly differentiated the crews from each other.
- **Evaluation:** Use the data to guide subjective evaluation of race results according to the eight factors. Reported race times must be reconciled in your evaluations, but the factors that led to the observed performance may be subjectively interpreted (perhaps guided by statistical analysis).
- **Experimental Designs:** Consider comparable crews to study, sometimes even evaluating the same identical crew in separate races. This controls the variability of some of the factors in the model and allows isolated factors to be evaluated more precisely.

The explanation for differentiated crew performance should be entirely explainable through the interpretation of these 8 factors as applied to a single race or to pairs of races involving the same crew(s). All times and time splits need to be reconciled while isolating the separate effects in seconds of each of these 8 component factors.

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