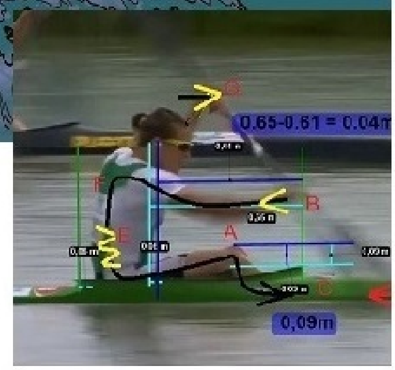
ANDREA PACE



Complements to the Base Technique in Sprint Kayak; Methods of Evaluation

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Summary

The following is a study on the methods of evaluation of complementary elements of Base Technique. These are:

1. **Meta-Technique** – which represents the athlete's primary objective and is closely related to the hydrodynamic characteristics and the statistical necessities of energy exchange; and
2. **Micro-Technique** – which relates to the specifics of force application with a view to achieving the desired objectives, using Base Technique as required.

We will also be examining the physical principles relating to the various evaluations, as well as providing the formulae and showing the methods of video-analysis employed.

With regards to the athletes' Meta- and Micro-Techniques, we shall evaluate some of the elements identified in the video clips. An athlete with flawless technique will produce physical phenomena that leave predictable and consistent traces, which in turn represent the optimal point of reference. It is not a coincidence that these traces and phenomena correspond to the principles of propulsion of naval hydrodynamics. On the other hand, an athlete whose technique is imperfect will produce physical phenomena that leave chaotic traces, which are never similar to those we expect to see in optimal cases.

We will also devote our attention to analysing races using GPS data for speed and frequency provided by the ICF (International Canoe Federation) and by the FISA (Fédération Internationale des Sociétés d'Aviron) for international races. It is possible to obtain a great quantity of information using said data: we can analyse information relating to quality, as well as indicating the fundamental 'methods' or 'modes'. We will see how the 'methods' used by champions correspond to those predicted by theory, whereas the 'methods' used by lesser-skilled athletes make no sense when viewed from the point of view of hydrodynamic propulsion.

Throughout this paper, I will be conducting qualitative studies of athletes' technique. When an athlete stops improving, the root of the problem often lies in a technical issue that hampers the process of optimisation. This is made evident by the studies conducted on many athletes who compete on an international level. Unsurprisingly, the qualitative behaviour of athletes who only compete on a national level will be even worse. Trainers will find H-Graph-based analysis particularly useful when training athletes who have stopped improving: in the space of just a few minutes, it will become clear whether or not there are technical issues. Once this has been established, one must then proceed to deal with the issues by solving them and ultimately finding a way to benefit from them.

Foreword

Notes for the reader:
The introduction (**Chapter 0**) can be rather difficult to understand, even for those of you who are familiar with the topics covered. I therefore advise you to either take a leap of faith, and proceed directly to the questionnaire or to **Chapter 1**, or to choose to attempt to study and comprehend the reasons behind the choice of the selected methods.

The term *stiffness* is used here to indicate the ability to resist elastic deformation due to an applied force. Athletes described as 'contracted', or 'rigid', means they are experiencing difficulty with one or more joints, with the muscles blocking the movement. In this case the movement is inelastic and the joint is unable to return the energy it has absorbed. Trainers should, instead, try training the athlete to uphold a harmonious and elastic behaviour, with the right amount of deformation proportionate to the load. This means having the right *stiffness*: stiffness = deformation / applied force.

For instance, in case of a 'well-fixed' joint, the stiffness value becomes very high. In this way, for example, the blocking of the shoulder girdles is determined at the very first stage of contact with water. If this is not done, and the leg muscles proceed to apply maximum strength, the athlete will most likely experience muscular contraction and ensuing myofascial damage. A lay observer may think that the athlete is too rigid, whereas the latter must instead simply determine the weak link correctly, and do so in a more rigid way – indeed with more stiffness in that joint. It is important to understand the subtle ambiguity of the terms 'rigid', or 'stiff' in order to avoid incorrectly training an athlete with stretching exercises when the primary cause of concern is actually an inability to block, which could be fixed by undergoing appropriate weight training exercises.

A further issue lies in the definition of the terms *efficiency* and *effectiveness*. In this context, an action is 'efficient' if it is carried out with minimal waste. It is calculated by looking at the relationship between applied power and necessary power. Efficiency is the decisive element in long-haul races.
On the other hand, an action is 'effective' where the interaction of the various components leads with increased ease to the achievement of a result. Effectiveness is decisive in shorter races, where a significant waste of energy can be justified if it means that time can be reduced even by just a tenth of a second. A clear example of this is the use of the legs in freestyle swimming – in longer races legs are not used very much, whereas in shorter races they are used much more, albeit for the purposes of an advantage in terms of time that is small when compared to the expense in terms of energy.

Contents

Chapter 0: Physical Phenomena Concerning the Relevant Evaluations and Questionnaire

Throughout this paper we will deal with the evaluation methods and the primary aims of technique. The issue of stiffness, instead, is part of the smaller details that make up the overall motion. This topic is mentioned at **paragraph 0.4**, and leaves scope for extensive research.

With regards to the various references made throughout the rest of this paper, these represent material gathered in consultation with Mr Carlo Vivio (*01) and Mr Jernej Župančič Regent (*04), who have a particular way of preparing these small yet crucial details, by making use of original exercises both in and out of water.

Contrarily to the theory, evaluation methods are very simple: in some cases they consist of just one single frame from video footage, upon which are traced coloured segments and numbers representing the differences between two or more athletes.

Unfortunately, focussing solely on a single criterion of assessment without knowledge of the whole theory and its relationship to other methods, may result in this research being perceived as an arbitrary process that leads to merely distinguishing some athletes' technical qualities.

We must, however, be patient: in deciding to avoid the formalism of physics, mathematics and hydrodynamics itself, we must accept that any phenomena corresponding to a theory can only be confirmed by methodical observation. A thorough reading of the whole document will demonstrate how lesser-skilled athletes obtain worse results on all evaluation criteria, and that the only athletes with perfect scores are Adam Van Koeverden in the K1 1000m in 2011, and the Croatian double sculls, the Sinkovic Brothers (in every appearance). In order to verify this yourselves, you can view the footage from Van Koeverden's London 2012 races – it is clear he no longer upholds the same behaviour in terms of quality, and, as a consequence, he comes in second and not first. For a trainer this may be sufficient, but it can be very time-consuming to read the material, read it again, watch the clips, and make up one's own mind.

Should you encounter a section with far too much information to be comprehensible, but also far too interesting to be left uncomprehended, please feel free to email me with your views and/or questions at **andreapacez@gmail.com**

The race model is displayed on a graph that can be quite challenging to make sense of. The graphs follow tables that display the corresponding data. In any case, these graphs will become easy and fast to consult once it is understood how they operate. All it takes is an investment in terms of time, and some initial blind faith.

The following is an example of a simple problem with a complex solution. Around 20 years ago, in 1996, several other trainers and I observed the movement of Holman's and Rossi's legs. The fact that, right at the beginning, the athletes' knees were virtually at the same height appeared to contradict the importance of legs in relation to propulsion.

Fig. 5.4 (**Chapter 5**) shows one of the athletes with the absolute ideal leg movement, namely Marko Dragosavljevic. He not only moves the knee of the 'counterforce' leg, but also lowers the other knee: this is already happening 3 frames (or about 0.05 seconds) before the paddle touches the water. This shows how all the elements of Micro-Technique, usually performed unconsciously, such as muscle preload, blocking, elasticity and trajectory handling, must be managed in a stable manner in all racing conditions.

This topic is widely ignored in the context of Base Technique, and, in fact, there are still no clear answers to the questions posed 20 years ago. Such a simple technical element like the synchronicity between the movement of the legs and the motion of contact of the paddle against the water is not acknowledged either in scope or with regards to the frame-by-frame differences of anticipation and delay of the single leg. Yet this phenomenon leaves '**clear traces**' on the clip.

I am sure there have been people who, decades ago, were asking themselves the same questions: indeed, a lot of athletes and teachers (for example, Dario Fogo), even more inquisitive than I, have guided and encouraged me in pursuing my research.

With regards to this matter I must add that many trainers are induced to think that athletes such as Pimenta and Stuart tend to under-perform in the final part of the 1000m races due to metabolic characteristics. There exists, however, the definite possibility that there is a breakdown in performance due to errors that, in conditions of fatigue, can no longer be compensated. In **Chapter 4**, we will analyse the races of two athletes whose performance issues are undeniably of a hydrodynamic nature.

0.1 – Meta-Technique

Technique can be separated into three parts.

0.1.1 Base Technique

The term Base Technique indicates the way in which the four stroke phases (preparation, attack, traction, and exit) are applied as determined by the trainer. This system, albeit being necessary in many water sports, is in itself not enough. If Base Technique is used alone, the athlete remains free to perform numerous actions with all parts of his body. This can only lead to a positive result for athletes who are naturally endowed with those skills that are not required by Base Technique; those skills that trainers cannot transfer to their athletes precisely because of the Base Technique's limitations.

From the athlete's point of view movements are performed subconsciously, using a mix of harmony, aquaticity and sensitivity. In this context, these terms have the following meanings:

1. *Harmony* – how the cyclical paddle stroke movement is performed and whether it is in harmony with the cyclical movement of the boat and the elastic elements of the human body and of the paddle itself;
2. *Aquaticity* – the ability to deal with the water surrounding the paddle;
3. *Sensitivity* – the ability to deal with muscular tension in the body and in contact with the equipment.

We must further consider that, in conditions of fatigue, certain elements – such as variations in available strength, stiffness, and synchronism – cause diverse propulsion trajectories, and this can lead to a rapid loss of efficiency and effectiveness in the movement.

0.1.2 Meta-Technique and Micro-Technique

The term Meta-Technique defines what are mainly hydrodynamic, mechanical and thermodynamic phenomena without which it would not be possible to obtain satisfactory results.

Micro-Technique, on the other hand, refers to propulsive muscular interactions coupled with muscular interactions relating to the harmonic equal distribution of energy.

Using the evaluation systems shown in the paper, we cannot observe and understand the physical phenomena of Meta-Technique, but we can measure its effects. We shall see in detail that these methods represent a system of evaluation that is both qualitative and quantitative. This system is tantamount to observing the tracks left by an invisible giant, i.e. physical phenomena we cannot see directly until the moment they become evident.

Some trainers have no need for this information, as they have the ability to choose the best angle to observe one phenomenon at a time. In this respect, observing some video footage of Nikola Bralic (CRO), I have become convinced that he would have no need to study the present paper. Indeed, his best crew (M2x Sinkovic Brothers) is currently being used as the point of reference to construct this entire method.

Some trainers correctly apply Base Technique and give the athletes a wide freedom with regard to all the rest, selecting capable athletes who already possess the necessary complementary skills.

The purpose of this paper is that of systematically utilising knowledge of Meta-Technique and Micro-Technique to ensure the success of lesser-skilled athletes, and likewise helping the more capable ones to adapt to new crews or to different-length races.

Other trainers, instead, use systems that are simply incorrect, for example adding extra details to the Base Technique and doing so in the wrong order. In this way, one may miss the chance to bring out natural talents.

We will see further on how the optimisation of a coefficient of naval hydrodynamics, known as the *coefficient of advance*, crucially affects Meta-Technique.

0.2 – The Equilibrium between Inertial Masses and the Dispersion of Energy

One element of Meta-Technique that is not too closely tied to hydrodynamics is the equilibrium between the opposing masses on the points where strength is applied. In kayaking, the way in which athlete apply force is subordinate to this task. The dispersion of energy in the case of disequilibrium is a 'statistical thermodynamic necessity', and energy is always absorbed by the point with the least inertia.

In the next few paragraphs, we shall see how water inertia and athlete inertia are balanced by modifying the length of certain levers. In addition to perfect balance, we might encounter two situations:

1. Where athlete inertia prevails, and there is a dispersion of energy in water with ensuing turbulence; and
2. Where water inertia around the paddle prevails, and there is a dispersion of energy in the athlete's body, more specifically in the muscles and/or connective tissues.

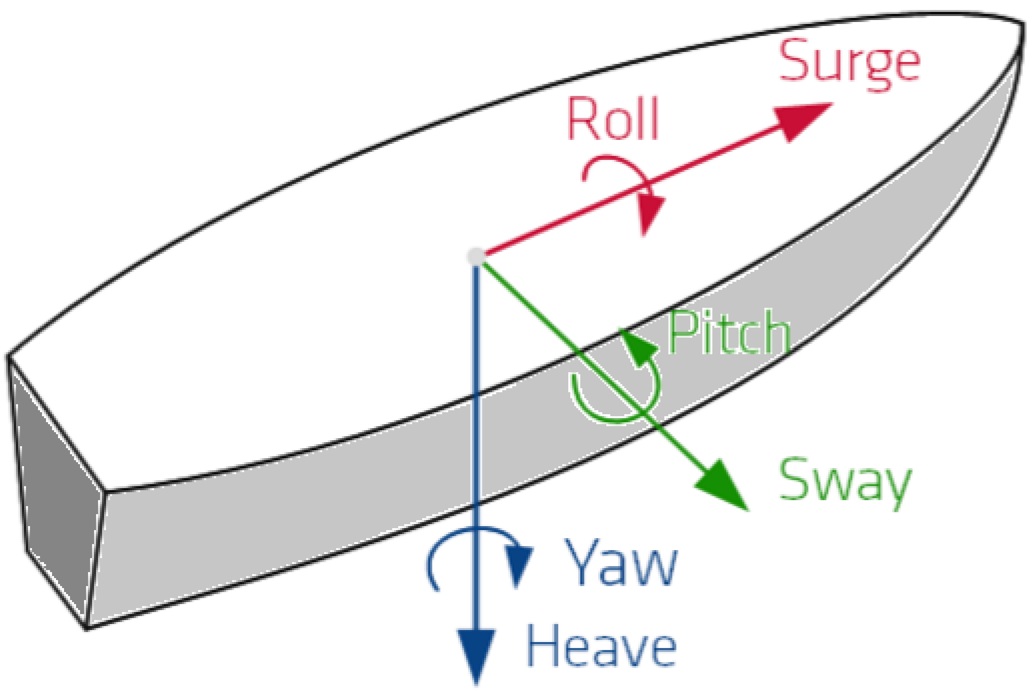
This type of information is crucial in order to be able to correctly regulate the boat settings in both rowing and kayak.

It may sound like a paradox, but it is precisely by increasing the inertia on which the force is applied that energy is dispersed within the athletes' muscles. This is a positive note for muscle hypertrophy training. However, when athletes fail to correctly set up the weak elements of the chain of force transmission, the dispersed energy damages the myofascial system. The result of this is that the production of testosterone is not stimulated, but the production of cortisol – testosterone's biggest enemy – is.

0.3 – The Cornerstone of Meta-Technique

The motion of the boat represents the cornerstone of all athletic movement in water sports. Moreover, it is the most important and sensitive element in Meta-Technique evaluations. This can also include swimming, if we consider a human body as a boat. Fundamentally, it is based on the assumption that if this element is optimised first, the rest will smoothly. Below, I will demonstrate this 'strange' phenomenon from the points of view of theory and naval propulsion.

The boat motions, as shown in **fig. 0.3**, are as follows:



[Fig. 0.3]

1. *Rotational motion*: roll, pitch and yaw; and
2. *Translational motion*: surge, sway and yaw.

The second element of Meta-Technique is water interaction. While this element is being optimised, the appropriate boat motions can easily be maintained precisely because they facilitate the correct interaction with water.

Finally, we will deal with the transmission of strength throughout the body. Once we get to this stage, we will have already optimised hydrodynamics, and we can concentrate on maintaining a balance of inertias, of the forces, and torques at play on the points of support. When put into practice this means that, if we develop strength and transmission abilities in accordance with principles of Meta-Technique, we will not run the risk of making mistakes.

0.4 – The Inertial Machine

When athletes learn technical movements on an ergometer, the results can be random. This happens for several reasons, the main ones being that:

1. The balance of forces is completely different to that of kayak; and
2. The balance of masses becomes impossible since, when using an ergometer, the legs' counter-mass is infinite, whereas on a boat the counter-mass is the weight of the boat itself. Moreover, the upper body's counter-inertia is represented by the ergometer's flywheel, which remains fixed and equal throughout, whereas when the athlete is on a boat the upper body's counter-inertia depends on the use of the paddle or oars.

Please see **Chapter 5** – where we will be discussing radii – for another preview on how the experience of training on an ergometer differs from that on an actual kayak. The use of a mobile cart as opposed to the braking part of the flywheel is essential to deal with inertia on contact with the feet, but it is necessary to build a regulating system that deals not only with the braking power but also with the flywheel's inertia.

With regards to the selective learning of technique – separating each element one by one – it is much more convenient to use a system similar to the ergometer which, however, allows the athlete to exercise his or her strength at will on the appropriate inertia with both arms and legs. This topic will be further discussed in a future publication that will introduce the balanced and harmonic elastic inertial machine.

0.5 – Advance Coefficient J

The most important aspect of any water sport is propulsive yield. In this respect, there are two fundamental notions:

1. Each propulsor has a maximum hydrodynamic efficiency level with a precise advance coefficient, shown with the letter 'J' in naval hydrodynamics. J is proportional to the advance per stroke when the percentage of time spent in water is constant (see **Chapter 5**); and
2. The inertia of the water mass involved in the action, which stabilises the grip of the water, is proportional to the radius to the power of 4.

The geometric equivalent of the advance coefficient J is the angle of incidence of the water on both sides of the paddles.

A kayak's pitch motion is usually limited to 1 or 2 degrees of rotation. The surge motion is not oscillatory but becomes cyclical thanks to the movement of the athlete's body. Both motions greatly influence the advance coefficient J. The angle of incidence of the water on the paddle – put simply, the way in which the paddle slides in and out of the water as it undergoes the propulsive action – will change significantly according to the synchronisation with the boat's motions. As mentioned in **para. 0.3**, we must first deal with these motions by synchronising them with the propulsive action, and then proceed to optimise the propulsion phase.

A clear example of when the procedural order is crucial could be a person who has to regulate the rear-view mirror of their car, and has to use a padded cushion in order to sit in a more ergonomic position.

In such a case:

1. The correct decision would be to position the cushion first, and to then adjust the rear view mirror accordingly;
2. The incorrect decision would be to proceed in the opposite order.

To complete the analogy with **para. 0.3**, the cushion would represent the cornerstone of this system.

As will be made clear in **Chapter 9**, there are several procedures that need to be completed in a precise order, starting from the boat and moving on to the paddle, and, finally, to the transmission of force.

Regarding the transmission of force, we can compare it to a musical instrument:

1. First we have a pianoforte, representing the 'completeness' of an athlete in a kayak;
2. Second we have an electronic keyboard, with particular attention given to the keys (touch-responsive): this corresponds to paddle on a boat which moves at the same speed as a kayak, but that is blocked in all its linear and rotational oscillations; and
3. Finally, we have a keyboard printed on a piece of paper: this corresponds to an ergometer.

What this means is that, when using an ergometer, one must not make the mistake of thinking that they have mastered the final skill, when, in fact, training on an ergometer is merely a technique used to isolate and fix specific problems athletes may be experiencing. A pianist can execute the Base Technique perfectly on piece of paper, and at the same time press his fingers against the printed keys with different speed, force and impulse for each note. He can afford to do this because he receives no feedback regarding the sound variations in volume and timbre.

This can be positive if the instructor means for the student to concentrate on only one detail, but it can become a problem if the student then automatically perseveres in carrying out the flawed actions that they were unable to dominate on ergometers. Similarly, a kayaker or rower can take advantage of the fact that ergometers are fixed to the ground – this way, any inertial thrust motion on the footrests will not penalise them, and they can apply greater force without actually gaining any real advantage once on board of an actual boat. Fortunately, in rowing at least, it is possible to make use of the special slides placed under the ergometer.

Whichever system is used to simulate movement in a gym, Meta-Technique is of the utmost importance and athletes must be able to implement it. This can only be achieved on a boat. Elements of Meta-Technique that, to the layman's eyes, may seem almost uninfluential can actually drastically modify Meta-Technique. These are:

1. Changing the vessel: each boat behaves differently with regards to linear and rotational oscillatory motions. In hydrodynamics the fundamental element that affects this dynamic behaviour is the mass added to the boat: basically, each boat's inertia increases proportionately to the mass of water affected by the movement under consideration;
2. Changing the crew's position: in this case also, the equilibrium of forces exercised by athletes in relation to their place on the boat can change dramatically even if the position is changed by just a few centimetres; and

3. Changing the area of water where training is conducted: in some cases maximum speed differences of one second for the T100 have been observed (T100 is defined in **Chapter 5** and it is the time taken to travel 100m at a given speed).

Since these modifications, which may appear trivial, have such significant effects on athletes, we can conclude that simulation devices cannot meet the demands of Meta-Technique.
The first element that must be optimised is the motion of the boat relative to the athlete and the paddle (or the oars). It must be a priority because it directly affects propulsive hydrodynamics: this explains why changing the boat or the crew's position always brings about big surprises.

Let us consider that on a crew boat, when the bow is high, the athletes nearest to the bow are also furthest from the water. This and other similar phenomena can explain why certain kayak athletes and crews obtain better performance with actions that may at first appear to be erroneous – for example, radius, angular sectors and different timing of entry and exit. These represent automated compensations that can lead to good overall efficiency, but may on the other hand limit further improvement. Moreover, when such compensations and sensations lead to success, athletes are unwilling to give them up. In order to improve, therefore, we must understand what error is being compensated by the visible actions and eliminate it.

The second element that must be optimised is the ability to have good water grip. In order to create the right interaction, the blade must enter the water unhurriedly, even at the highest of frequencies. It is always necessary to allow the water around the paddle to create the large mass of slow-moving water that allows the blade to slip upwards out of the water creating a force in the horizontal direction.

The third element that must be optimised can be simplified in Base Technique terms: after the paddle or oars have entered the water, the athlete must continue holding these in the smoothest way, with no tugging or jerking motions, which is what we see happening with the best athletes. We will soon see how inconsistencies can be produced by many factors that are the key components of Micro-Technique. I will be assessing these further on.

All the Macro- and Micro-Technique methods of evaluation have been created for those trainers who want to give their athletes the possibility to improve from a technical point of view. The athletes must acquire the skills they do not have, and at all costs avoid situations where there may be saturation. The use of such evaluation methods remains silent on the topic of how to achieve athletic perfection – this will be our main objective, although we know it is impossible to achieve in a definitive way. These evaluations, therefore, are useful for trainers who have the ability to convey to the athlete the right approach to tackle the diagnosed issues. The problem could be banal, like a paddle that slides in the water, but the solution can be complicated since, as we have seen, we must proceed with order starting from the movement of the boat and, in particular, the relativity of movement between boat and athlete (pitch and surge, **para. 0.3**). Trainers all too often advise athletes to perfect certain details, while neglecting the fact that they must first perfect the base.

0.6 – Static and Dynamic Behaviour of Forces Applied to a Lever

When applied to a lever, dynamic actions follow different physical laws than static forces. Static forces in relation to levers have linear balance, whereas in the case of a force that produces displacement, the part of it relative to the acceleration of a mass in a circulatory motion depends on the square of the length of the lever. For complex reasons, the inertia of water interacting with the paddle depends on the length of the lever to the power of 4.

Below, we will proceed to define only the fundamental levers called Radius 1, 2, and 3, together with the advantages and disadvantages of each of their settings. This concerns both kayak and rowing, and, moreover, the same problem can be encountered in the human body itself, where small postural displacements can make a great difference both from the point of view of impulsive behaviour, and the regulation of stiffness and time required to fix certain joints.

0.7 – The Three Radii

Adjusting the levers on which to apply force represents a serious challenge in both rowing and kayak. The optimisation of levers in rowing can be very time-consuming, whereas in kayak one can, theoretically, 'give it a shot' with each stroke and, unfortunately, this can happen during the execution of the stroke itself.

[Fig. 0.7]

We shall see in **Chapter 5** how three simple levers in kayak represent a way to satisfy all situations, and that their relative variations cannot be selected at random, since for each erroneous combination one will experience a precise negative physical phenomenon.

The three radii are roughly shown in **fig. 0.7**. Please note that Radius 2 is an element that increases constantly from the moment of immersion to that of exit.

While setting up a rowing boat or kayak, one will primarily attempt to optimise the principal lever, seeing it as a transmission ratio the result of which is the optimisation of stroke frequency. Unfortunately, there are an infinite number of different settings that lead to the same stroke frequency, and only one of them results in maximum performance, and another in maximum efficiency.

Advancement per stroke depends mainly on:

1. The radius of curvature (Radius 1, 'R1' in **fig. 0.7**); and
2. The angular sector of the oar (or paddle) during traction (**Chapter 5**).

In order to optimise propulsive action, it is necessary to know what can happen with the overuse of Radius 1 or the sector. These two elements are the basis for optimising everything and at the same time avoiding negative physical phenomena.

The radius and the angular sector are not directly related to hydrodynamics: a skilled athlete can adapt to an erroneous setup without producing negative hydrodynamic effects. In such a case, we would move on to regulating the levers so as to have the correct ratio of transmission.

It is wrong, on the other hand, to try and regulate the ratio of transmission while ignoring the physical phenomena of hydrodynamics. For instance, it would be a waste of time to attempt to find the optimal ratio of transmission if, when in water, the oars or paddle should slide.

The next few chapters will not be concentrating on Radius 3. Radius 3 is, essentially, the height of the hand exercising traction relative to the centre of the submerged portion of the paddle. We can see this lever as the radius of rotation of the paddle relative to a fixed point in the water.

The choice of Radius 3 is a compromise the athlete makes to meet technical requirements together with the force load that his or her torso muscles can withstand. The smaller Radius 3, the more the hand exercising traction is low compared to the athlete's centre of mass: this in turn facilitates the muscles that have to work to stabilise the torso relative to the pelvis.

A fast submersion and a wide grip reduce Radius 3, which in turn can damage performance. However, imposing a high Radius 3 on an athlete can be counterproductive if they do not yet possess the strength to handle it.

0.8 - Harmony

Chapter 8 deals with the most complex topics: harmony, ineffective acceleration and energy recovery. The overall motion is compared with the intended harmonic motion and the differences between the two are analysed:

1. Athlete delay: the athlete dispels energy inwards (in an introverted way), and, instead of pulling forward, winds up pushing backwards (intra-push);

2. Athlete ahead of time: the athlete is not reaching his or her highest efficiency level but is pulling forward during the active stage. The energy wasted does not disrupt the athlete since it is in the direction of the boat's motion (extra-pull); and
3. In the best-case scenario, the athlete is on the mark or only slightly ahead of time, harmoniously distributing the kinetic energy in elastic energy with maximum efficiency and effectiveness.

0.9 – Switching Off the Warning Light

When an athletes perform a movement that appears to be different from the usual technique used, it is probably because they are no longer able to compensate an error that can be hard to spot: we call this a 'warning light'. Trainers can respond in one of two ways:

1. The narrow-minded trainer – will focus solely on the unusual movement, trying to get rid of it. This is clearly wrong, as they are failing to realise that the warning light can work in our favour;
2. The open-minded trainer – will look for the true cause of the problem by exploiting the warning light itself. Once the real problem is solved, the warning light will go out. By learning the possible causes behind the particular error, we can easily find a solution.

Throughout this paper, we will mainly analyse first-rate athletes (selected from the A Finals of world cup races), but the evaluation methods used can also be applied to lesser skilled athletes.

However, we must take different measures depending on the athlete's level of skill:

1. Low-level athletes: before we can even think of being able to balance all the fundamental phenomena that occur on a boat, we must first build up the entire mechanisms of Micro-Technique in the gym. This paper is full of information on what happens when parameters are modified – for instance, what happens when we modify Radius 1 and Radius 2. Therefore, if we do not know the ideal settings for an athlete or crew, we must find these out by trial, by changing one parameter at a time, with a view to perfecting the core physical phenomena that athletes see or perceive.
2. High-level athletes: we must observe the athletes and film them right at the moment when they get into trouble; at that point the flaw (the warning light) will be easier to spot. In this case also, it will be useless to try getting rid of the warning light directly, as the root of the problem remains even when we are unable to see this warning light. At that stage, athletes still have the energy to compensate this phenomenon, and are motivated to do so in order to minimise damage and to retain the effectiveness of the action. We can see, therefore, that eliminating the root of the problem is not easy: trainers must find a way to fix the error by finding its cause and making it observable, and, in order to do so, athletes must stop compensating for this error. In this way we do the opposite of trying to 'switch off' the warning light. During technical training we can ask athletes to disregard movement effectiveness and compensation of error in order to work on efficiency.

When athletes make only one mistake, it would be incorrect to merely fix the visual appearance of the error. In cases where there are two mistakes, and one is dependent on the other, the situation is even worse – generally, the warning light we see will only show the second of the two, whereas our aim is to fix the first of the two errors in order to eradicate them both simultaneously.

In the most complex cases it is necessary to start over, and to do so we must make use of Meta-Technique. In this case, the athletes' or crew's level of skill does not allow for a quick fix, and the best advice is to start over from the cornerstone (**para. 0.3**) and to do so on small boats (K1 and K2 for kayak, and 1x or 2- for rowing).

One of the physical phenomena that affect Meta-Technique is directly linked to Micro-Technique, even outside water: the surge motion of the boat compared to the athlete. This element is so important that it deserves to be isolated and perfected at the gym – it can be achieved by using the adequate ergometers or inertial machines (**para. 0.4**). In this way, it will be possible to optimise the headway motion issues between athlete and boat without having to worry about any issues concerning water grip.

To tell the truth, we can actually achieve the same objective on a boat by doing as follows:
1. First, concentrating on the issues of Micro-technique to optimise boat motion while ignoring the behaviour of the paddle in water; and
2. Second, as soon as the first point is completed, water grip will be a much easier issue to solve as it can be construed in sync with the boat motion (**para. 0.5**).

We can further explain the point made at **para. 0.5**, regarding the interaction between water grip and boat motion, with a simple example: visualise a glass on a table and a person who has to pour water into that glass. If the table is on a boat that is out at sea and the sea is rough, the person must first establish balance so as to allow them to hold the bottle still with respect to the glass, and only at that point can they proceed to pour the water into the glass.

Unfortunately this phenomenon cannot be readily experienced by everybody as, in the case of low-level athletes, they will be stuck inside the kayak in a very uncomfortable way, and will only be able to move backwards (intra-push), and therefore any further movements that they could make would be unbalanced and could only serve to make the situation worse. Managing the boat motions effectively means, above all, to be in a comfortable position for each and every movement without losing balance (**para. 8.1**).

0.10 - Questionnaire

Trainers are more likely to achieve better results by using methods that they have mastered to perfection. We can only use other people's methods once we have completely understood them. We can, however, use the present material as a basis for discussion: the following questions can be a valuable incentive when discussing training with athletes or other trainers in a 'subtractive' manner.

That is, before we start innovating, to slowly begin to abandon methods that, despite having enabled the achievement of victory in the past, do not allow for further improvement. As argued by Jernej Župančič Regent in his trainer's manual (*04), if we wish to climb the highest mountain but end up on a hill, the best thing to do is to start over: in this case, 'subtractive' means coming down the hill, and locating the highest mountain peak before attempting the climb.

- A K1 W 200m completes the track in 40.0", passing the 100m line in 20.1" – is this a race with constant speed? (**Fig. 1.1**)
- In the last 250m of a 1000m race, a crew increases frequency to maintain speed: does this behaviour pertain to a high-, mid-, or low-level crew? (**Fig. 2.2**; **fig. 3.2**)
- Considering the three phases of paddling (start, centre and end), in which of these phases does the paddle have a higher angular speed? (**Fig. 7.2**)
- Do athletes maintain a certain fixed speed for the majority of the race? (**Chapters 1**, **2**, **3** and **4**)
- Do athletes maintain a certain 'mode' for the majority of the race? If so, is it quantifiable? What is it? (**Chapters 1**, **2**, **3** and **4**)
- When in a 1000m kayak race, or a 2000m rowing race, athletes increase speed for tactical reasons, how do they proceed to do so? Is it possible to define this 'mode' mathematically on the basis of speed and frequency? (**Chapters 2** and **5**)
- In a kayak K1, an athlete weighing 80kg moving at a speed of 5m/s is subjected to a brake force equal to 7kgf. In the aerial stage, does the athlete have to push the vessel forward with a force of 7kg? What happens if the athlete does not apply force on the vessel during the aerial stage? (**Fig. 7.1.5**)
- What are the effects of training with a hydrodynamic brake? (**Chapter 8**)
- Proceeding at constant speed, if athletes move at 80 strokes per minute ('spm') rather than at 100spm, do they need to apply more strength? (**Chapter 5**)
- An athlete who applies force on a boat with a higher speed utilises greater power. Is this positive or negative? (**Chapter 6.1**)
- In athletics, advancement per step (stride) is greater the faster the race: is this also the case in kayak? Why? (**Chapter 5.1**)
- If the boat is slowed down by water with a 7kgf, what amount of force must the athlete, on average, apply on the paddle? What does the average amount of force during the water stage depend on? Is the amount of force on the hands greater than 7kgf? (**Para. 5.1** and **Chapter 8**)
- Some kayakers are weak at the initial stage of the race, and stronger during the later stages, or vice versa. From the point of view of force application, what it the difference? (**Chapter 8**)
- Many athletes will hold the paddle underwater 65% of the time. What changes if they keep it submerged 55% or 75% of the time? (**Chapter 8**)

0.11 – Chapter Order

Chapters 1-4 deal with the processing of GPS data taken from a number of international races. H-Graphs are used to define the parameter of energy per stroke, thus removing any uncertainty that may arise when parameters are not seen as a whole. The letter 'H' has been chosen to honour Heisenberg's Uncertainty Principle.

Chapter 5 deals with those parameters measurable through the analysis of race video footage. We will conduct a quick analysis of the problems encountered in our reference athletes: these measures are known as Step 1 and Step 2.

Chapter 6 concerns one of the most uncommon things one can see on the video footage: the transmission of power and the equilibrium of inertias. Two videos are used in which the dynamic phenomena are evident enough so as to be visible to the naked eye and numerically calculable. We will also see an example of how dynamic phenomena can be assessed by using inertial sensors. This is one of the few instances in which the 'invisible giant' (Meta-Technique) is carefully examined: this way, we can link the various events with the more apparent 'traces'. If, at a later point, we encounter the same traces – even if these should be less evident – we will, without a doubt, know the identity of the phenomenon that we are observing.

In **Chapter 7** I will be using the analyses known as Step 1 and Step 2 on the same athletes studied in the H-Graphs of Chapters 1-4.

Chapter 8 deals with the most complex topics: harmony, ineffective acceleration, and the recovery of energy not used for propulsion.

In **Chapter 9** we will go back to the initial aim, and present a RoadMap to monitor its achievement. Finally, we will go through the principal training needed to understand and perfect the various elements.

Chapter 1: The H-Graph – the Graphic Representation of Race Models and Tactics

Example race: World Cup, Duisburg 2016, K1 W 200m Finals A

To facilitate the comprehension of the present material we will start, at first, with a small bundle of information to which we will gradually add all available data until we can easily make use of an H-Graph. By the end of this chapter we will have seen all that information which, were in not for this method, would be completely ignored.

The race I will use as an example is the 2016 Duisburg World Cup, K1 W 200m Finals A. (Link: https://youtu.be/lPmEQkjmnvY?t=37m10s).
The NZL athlete won the race with a time of 38.9", passing the 100m line at 20.1". At first glance this would look like a progressively-conducted race.
The UKR athlete was placed 7th with a time of 40.0", also passing the 100m line at 20.1": at first glance this would look like a constant-speed race.
Let us now examine a number of intermediate race values. We will add the figures for speed and frequency that have been taken from the table of GPS data published by the ICF.

Table 1.1 (NZL)

	Time		speed (m/s)	frequency (spm)
50m	11.1"		5.6	150
100m	20.1"	(9.0")	5.5	152
150m	29.3"	(9.2")	5.4	150
200m	38.9"	(9.6")	5.0	140

This may deepen our understanding a little, but there is still a lot missing. Suppose that we now want to check the figures for every 10m, and that we also want to see data relating to:

- Advance per stroke;
- Energy per stroke;
- Power;
- Relative variation of some of these parameters;
- Differences between various athletes at certain points of the race; and
- Verification of the race segments in which the athlete exhibits one of the typical race modes in which the following values remain constant: advance per stroke, energy per stroke, frequency or speed.

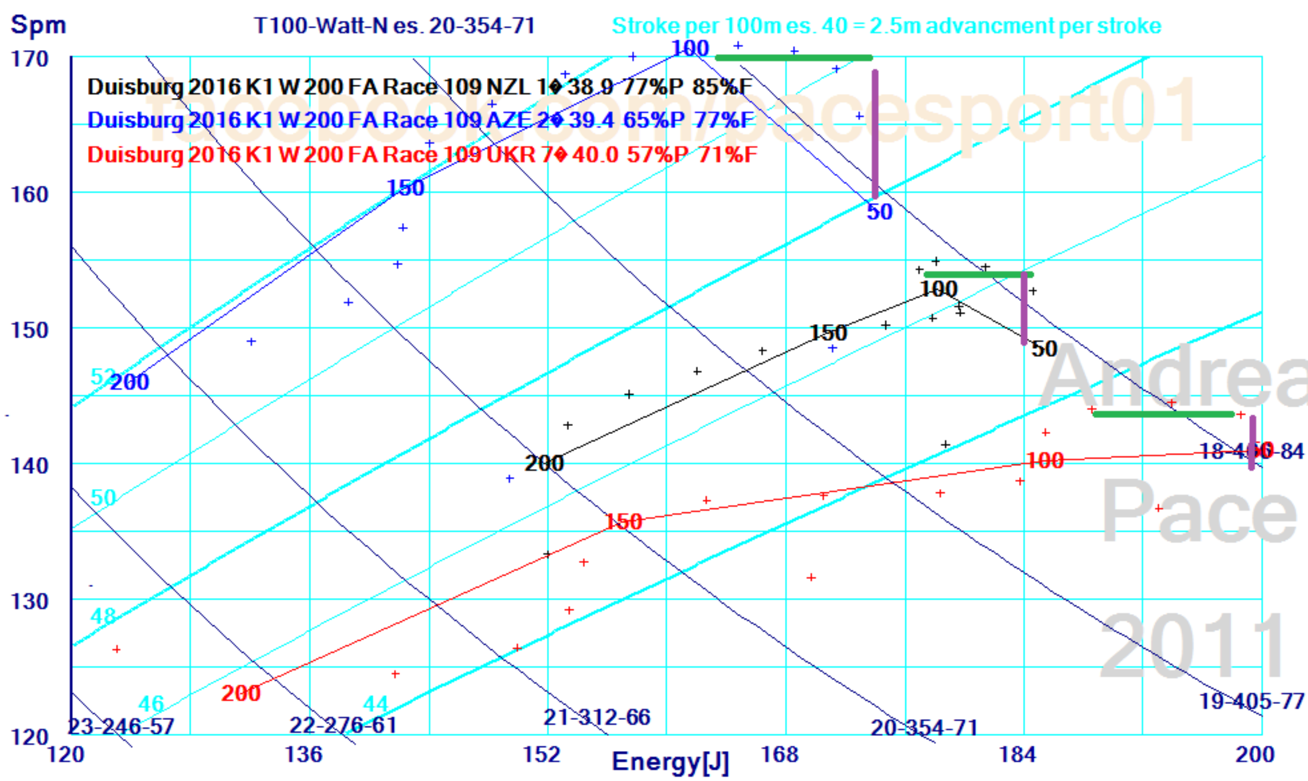
All of these elements can be shown on a graph, namely the H-Graph, which, as mentioned above, borrows its initial from Heisenberg in honour of his Uncertainty Principle. But why the

Uncertainty Principle? Because the energy per stroke is computable as the product of the Average Force per Stroke and Advance per Stroke: therefore, for merely one value of energy per stroke we have an infinite number of combinations of its factors.
Note that energy per stroke is a good indicator of strength only for those athletes who use the race mode of constant advance per stroke. For all other race modes, instead, it is an undetermined indicator and an H-Graph is necessary.

The force that the athlete must transfer to the system (athlete + vessel) at a given speed depends on four elements:

- Speed;
- Acceleration;
- Percentage of duration of the active stage (from now on, ‘percentage of time in water’ or ‘%tWater’); and
- Hydrodynamic efficiency.

Therefore, it is arbitrary to argue that energy per stroke represents the force applied in water. Using only the figure for energy per stroke, while ignoring the above four variables, will lead to assessment errors.



[Fig. 1.1]

In certain cases, the most important figure is the percentage of time in water – we shall later see why. This element can be inputed in the graph although we have not used it for our examples.
In this chapter we will use data for energy, force and power taken from certain formulae presented in **Chapter 5** (**para. 5.1**).

Let us now take a look at **fig. 1.1** (Duisburg 2016 K1 W 200m FA Race 109) which shows the H-Graph for three athletes:
NZL 1° 38.8"; 77%
AZE 2° 39.4"; 65%
UKR 7° 40.0"; 57%
The percentage value next to the achieved final time is a generous estimate of the power manifested in the last few metres compared to that manifested in fastest race segment.
The UKR athlete has been selected to portray the noticeable deceleration occurring in the race's final segment: quite the opposite of the constant-speed race which was assumed to be the case when looking only at the timings of the crossings of the 100m and 200m lines. In the final segment, the athlete is left with less than 57% of the maximum power demonstrated 30" earlier.

From the H-Graph in **fig. 1.1** we can deduce several important pieces of information. We can use these to learn how to read the values of the graph itself:

- The three athletes cross the 100m line at virtually the same time. This is shown on the H-Graph: observe the 50m and 100m tags, which are situated very close to the constant-speed hyperbole depicting 18" on 100m. T100 = 18", corresponding to a power of 466 Watts and an average force per stroke of 84 Newtons (as we shall see in the formulae below).
- Between each pair of coloured tags, which represent the marks for every 50m of track, there are four '*x*'s indicating the marks for every 10m of track.
- As you may notice with regards to NZL (black) and AZE (blue), between the 50m mark and the 100m mark there is no difference in speed, just a respective increase of 10spm and 20spm. We can, however, see from the 10m figures that there has actually been an increase in speed, and therefore the large increase in frequency is justified.
- For reasons of numerical analysis we must study the data between 50m and 100m with the help of two segments.
- Because of the above, the segment between 50m and 100m is better approximated with two segments: the purple segments represent the constant energy per stroke mode, and the green ones represent the constant frequency mode.
- Beyond the 100m line we move on to the stage where efficiency is the most important parameter. Ship propulsion theory tells us that there is only one value of advance per stroke with which the athlete can obtain maximum efficiency (same as the 'advance

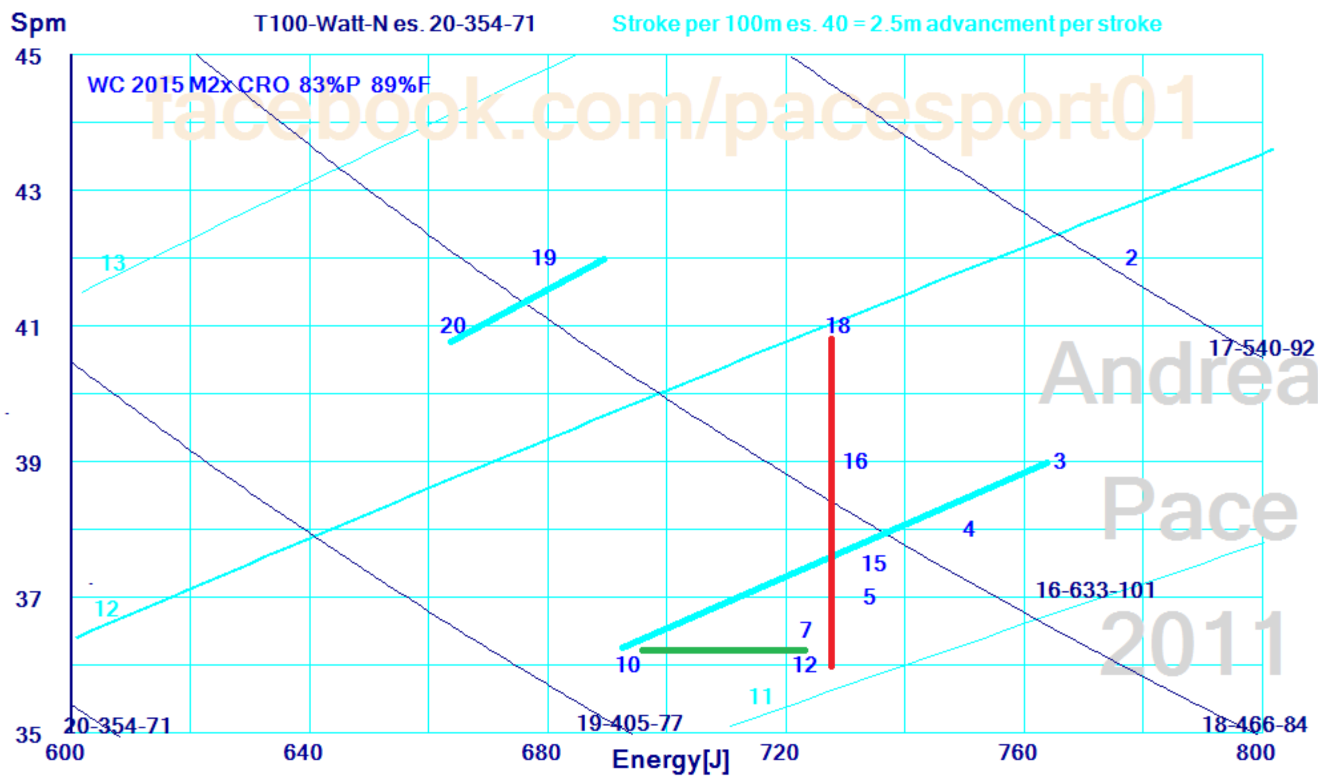
coefficient', unless we change the %tWater, see **para. 0.5**). Rather than giving the advance per stroke in metres, it is preferable to give the number of strokes per 100m (for example, for an advance equal to 2.5m, n100 = 100/2.5=40). The coloured marks for each athlete are arranged parallel to the cyan lines. The AZE athlete proceeds with a smaller advancement of 52 strokes per 100m; the NZL athlete with 46.5 strokes per 100m. The UKR athlete does not use this efficient mode, and she is, perhaps unsurprisingly, the slowest of the three in the last metres of the race.

- To assess each athlete's final speed in the 200m, it will be enough to read the T100 value on the closest blue line: 20" for NZL (meaning she ends the race with a speed 100/20=5m/s), 21.3" for AZE, and 22.2" for UKR.
- We can easily spot during which segment the NZL athlete wins the race: in the segment between 100m and 150m her T100 decreases only by 0.5" seconds, whereas that of the other two athletes decreases by 1.5". This means that in those 50m the NZL athlete gains 0.5" on the other two.
- Some think that the athletes that use a higher advancement are better from a technical point of view, but keep this in mind: the UKR athlete proceeds with a greater advancement compared with the other two, but throughout the race she does not use any gait modes in a constant manner, as a matter of fact the figure for her advancement changes every 10m. This shows that advancement is an important parameter, and the athlete must find and use the value which corresponds to the highest hydrodynamic efficiency, and should not change it on the basis of feeling or tactical needs.

Hydrodynamics itself cannot tell us what is the ideal advance figure for each athlete, but it does tell us that there is only one advance figure that corresponds to maximum propulsive efficiency. If an athlete constantly changes this figure the result will be lower efficiency. We will see that in 1000m races there can be two constant-advance race segments, and in this case there can be two different figures for advance. Here the athlete's skill will lie in being able to adjust certain technical parameters so as to obtain high-level efficiency in both segments.

Chapter 2: The H-Graph and Rowing – the Reference Models, Aguibellette 2015 M2x FA, L4- FA

We will now take a look at a 2000m rowing race in which athletes are distinguished not by their frequency figures but by their modes of proceeding.
We selected the best crew for the dual purpose of simultaneously studying both a winning crew, and a crew that represents the best possible expression of hydrodynamics. Moreover, the athletes weigh 82kg and are 1.84m tall: this is a further asset for a rowing crew, as athletes' weight can be of great advantage.



[Fig. 2.1]

Fig. 2.1 shows the M2x race of the Sinkovic Brothers (World Championship 2015 M2x Sinković - link https://www.youtube.com/watch?v=OWJw3wtQpK4). The crew overlooks the race from 2nd place, before taking the lead three-quarters of the way through, and keeping it till the end.

Note that GPS data for the first 200m is unreliable. Therefore, we can only assume that, until the 250m line, the crew progressively decreases its frequency until the 300m line (tag no. 3), with an advance per stroke value of 11.3 strokes per 100m (hereafter referred to as 'n100'; e.g. n100 = 11.3). From here, the crew proceeds with a constant value of advance per stroke, up until the 1000m line, after which there is a 200m constant-frequency acceleration segment (taking us to 1200m) which has two purposes: increasing speed and finding the optimal value of energy per stroke to increase frequency. From 1200m to 1800m there is a continuous increase in frequency with a constant value of energy per stroke (730 Joules). Towards the end of the race, they go back to a constant advance mode.

From a technical point of view, it is important to note that the cyan and red lines connecting the data gathered from the race intersect the T100 = 18” hyperbole at three points, corresponding to distances of 450m, 1550m, and 1950m respectively. The crew proceeds at the same speed along all three points, but with a big difference in terms of what they are doing dynamically at each point, and also a difference in terms of n100 values, which are 11.3, 11.5, and 12.4.

For training purposes, therefore, the margins of technique and the adjustment of levers must allow the crew a good level of efficiency for the T100 = 18” speed, both at a frequency of 38spm and at 41spm.

From the graph we can infer the following information:

- The training sessions in which the crew proceeds at maximum power can be performed at 780 Joules – this is the figure used in the first 250m;
- We can use different combinations for frequency and advancement corresponding to 730 Joules when we are working on training the athletes on that segment where there is an increase in stroke frequency, like the section between 1200m and 1800m in the race;
- With regards to the constant-advance segments, the most important one is that with a value of n100 = 11.3 strokes per 100m, as it is used for almost half of the race; and
- Finally, in the last 200m of the race, despite the conditions of tremendous fatigue, the crew manages to proceed at a constant-advance mode: this is very different from the previous segment (also cyan-coloured), since the speed is the same but the frequency is higher by 3spm.

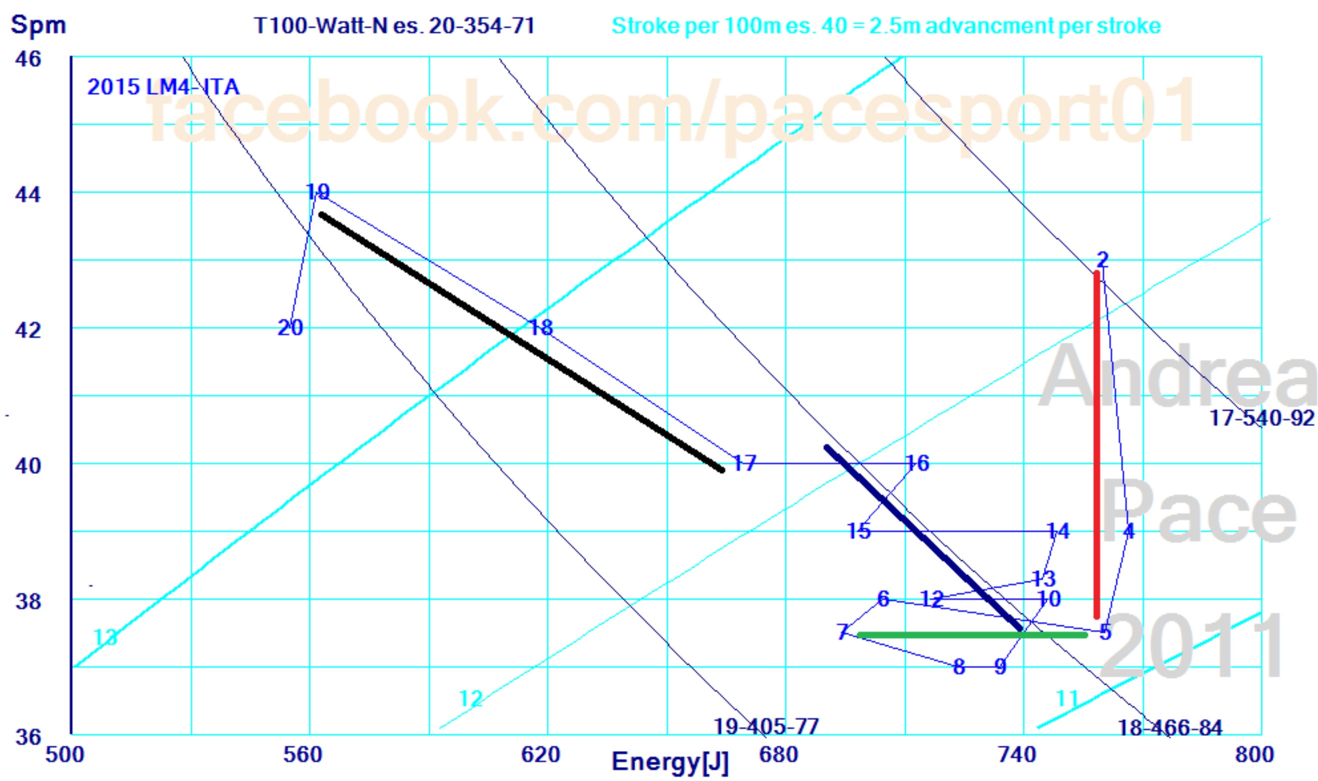
We do not know how this particular crew trains, but these figures represent a reference for anyone who wishes to imitate these champions.

One point must be made clear: throughout the entire race athletes must never proceed at constant speed. In the next few chapters we will see that those who do so end up losing: it may seem like a paradox, as one can assume any trainer would urge their athletes to maintain speed at those times when they are not increasing it, but this can only be of benefit if done in the right way and at the right time.

Analysing technical movements during the various stages of the race would allow us to find out how athletes implement the various race modes, but this is not possible since the available videos do not allow for further analysis.

In just a few words, and with a small preview relating to certain parameters that will be more fully explained below, we can describe the technical behaviour of this crew:
A boat's pitch motion is a limited phenomenon – when entering the water, the brake force exercised by the reversal of the athlete's motion by means of the mobile cart is minimal, as it only begins once the oars get a good "grip" of the water. At the end, the boat nose does not drop until the oars are out of the water. The oars show no sign of turbulence in the rowing stage; the figures for the slipping of the oars in water are null, or even negative.

We will now examine a Final A crew presenting a slip equal to 20cm. In this case, before the oars slip out of the water, the boat's nose quickly drops: this is due to an action which makes it impossible to re-use the energy of the torso's rotational impulse. The rotational impulse must be transferred to the whole body by using the tip of the toes as support, in order to find the right reduction of weight on the cart (see **Chapter 8**). In the present video we can also notice turbulence around the oars.



[Fig. 2.2]

As mentioned above, if hydrodynamics is not optimised we can expect problems to arise in relation to the race's tactical execution. **Fig. 2.2** shows a completely different H-Graph compared to the one selected as reference in **fig. 2.1**. It is the H-Graph for crew LM4-ITA, Aguibellette (FRA) 2015.
The constant energy per stroke mode is used only in the first 500m, after which, instead of an efficient constant-advance stage, we see a constant-frequency stage. Along the segment in which frequency is normally increased (from 1000m to 1600m), the crew proceeds at constant speed, increasing the strokes from 37 to 40. At this stage more than others, the crew show their inability to perform according to the desired tactic, proceeding at T100 = 18" (the closest blue hyperbole). Later on, a further increase in frequency, from 40 to 44 strokes, leads to a reduction in speed, reaching T100 = 19".

We have therefore examined the optimal case study, the M2x, in which we have seen a tactic that is used in many 1000m kayak races, along with an excellent implementation of hydrodynamic behaviour in both boat an oars. All this is due to a correct and, most importantly, wholesome construction of technique. By observing the points of view of the training videos uploaded to YouTube by the Croatian trainer Nikola Bralic, we can see how each detail is impeccably under control, thanks to the optimal choice of camera angle. For the purpose of avoiding formulas and physical-mathematical models, here is a summary of the active stage given in dynamic terms, rather than the usual references to the athletes' position:

1. The mere movement of the arms (stretched out) creates water grip;
2. The balance of mass and forces at play in relation to the water right from the very beginning; and
3. In the final part, the athlete or crew will carry out 'partial suspension', meaning they will take weight off the seat so as to give the oars enough time to complete the manoeuvre before the boat nose drops.

It is easy to define the technique of such a crew: they carry out an extremely complex motion, but do so with just a few flowing and harmonious actions. To *maintain* that level of skill Base Technique is sufficient, but, in order to *reach* it, Base Technique is not enough. For it to be enough, it would be necessary to have all the complementary skills already 'built-in' in one's DNA.

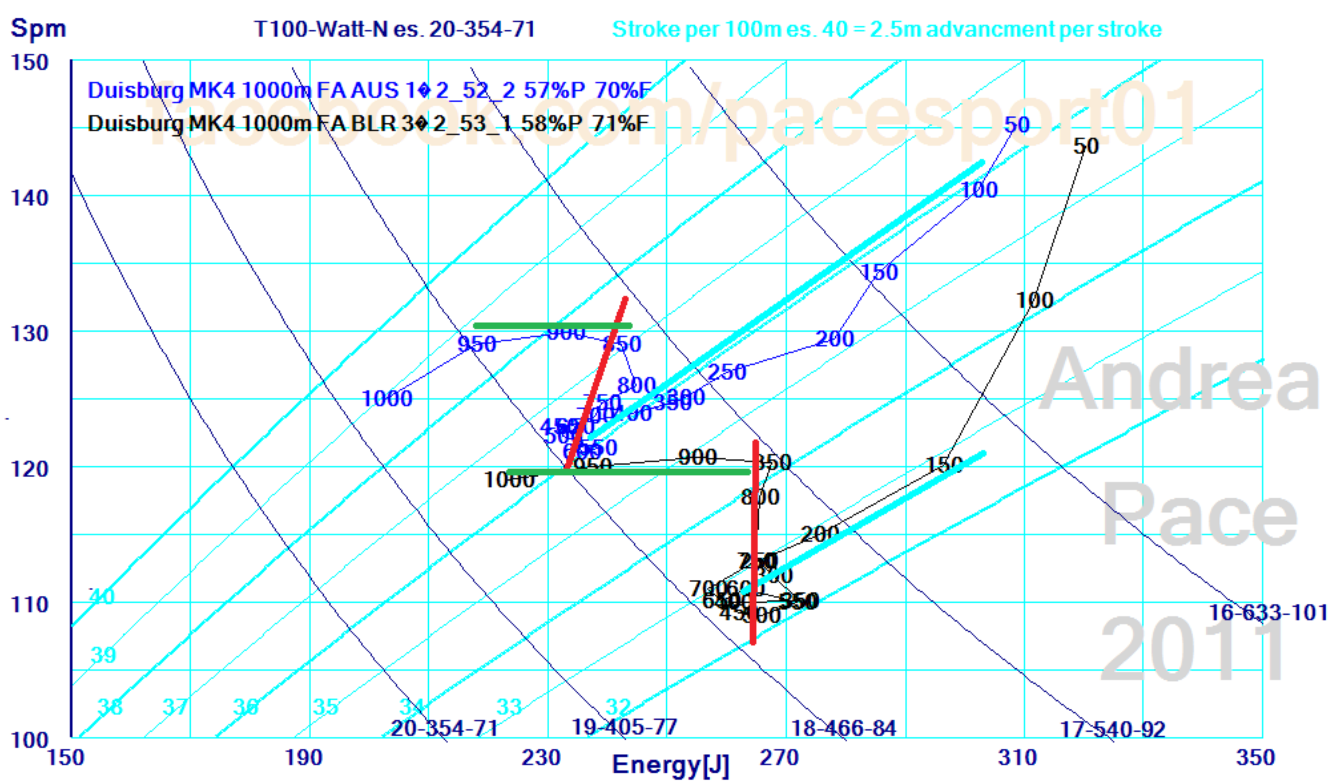
For purposes of verification, we will study the case shown in **fig. 2.2**, the LM4-ITA's race in which everything went wrong: the slipping of the oars, the boat's pitch, and general race technique; from mid-race, all attempts at increasing the frequency failed to bring about any increase in speed. The following approximate calculation will demonstrate just how much damage oars slipping by 20cm can cause: if we add a 20cm slip to every stroke, we will have to travel a further 48m, and the crew will have lost 8" in which it could have travelled a further 44m. Clearly, when the oars are not slipping, additional force must be applied, and therefore the above calculations have been approximated by excess, but, notwithstanding this, the idea remains that, had there been no oar slipping, the crew could have actually won the race: this can be an exciting and very motivational thought for athletes.

Chapter 3: The H-Graph

Kayak: Duisburg 2016 K4 M 1000m FA

Fig. 3.1 shows the H-Graphs (GPS data taken from ICF) relating to the first-placed (AUS) and third-placed (BLR) crews. Leaving the details aside for now, we can see there is a noticeable difference between the two crews: the K4 AUS proceeds at n100 = 36 (i.e. 36 stokes per 100m), whereas K4 BLR proceeds at n100 = 33. Both crews proceed along the 200m to 600m stretch of race using a constant-advance per stroke mode, and it is assumed that each crew proceeds with good efficiency according to the chosen mode of advancement.

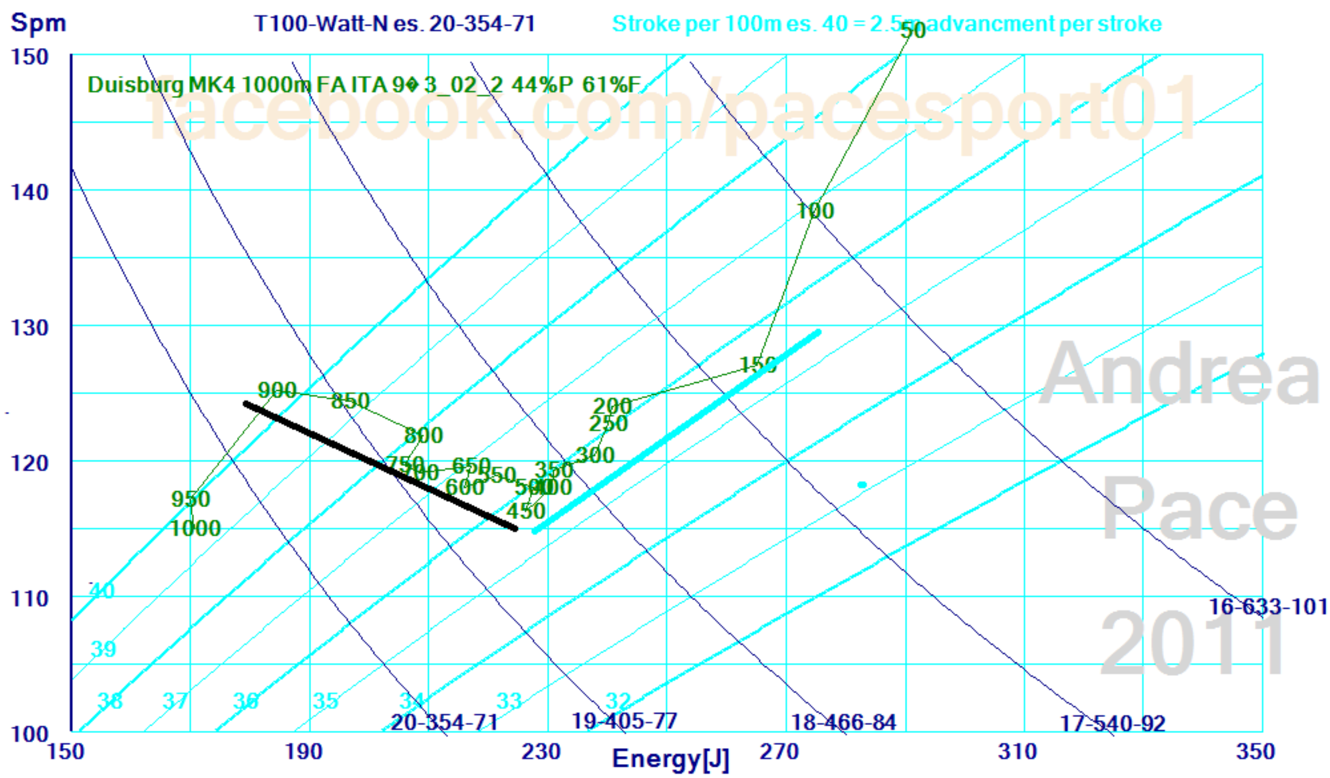
The section marked with red lines, in which frequency is increased while maintaining a constant energy per stroke, occurs between 600m and 800m. The BLR crew performs this stretch with constant energy per stroke (260 Joules), whereas the AUS crew begins this progression with a lower energy value (235 Joules), and simultaneously increases both energy and frequency.



[Fig 3.1]

Fig. 3.2, below, shows the H-Graph relating to the crew placed last in the same race (ITA). The advance per stroke in the first 500m is equal to n100 = 36, the same as K4 AUS. Once again, we can see that the difference between a winning and a losing crew is not solely imputable to the stroke frequency, but includes stroke frequency variations.

After 500m, the K4 ITA attempts some kind of action the result of which is only a slower rate of deceleration: the black line shows the segment in which, going from 118spm to 125spm, the T100 decreases by around 1” (from 18.5” to 19.5”). In the same segment, the other two crews increase the T100 by roughly the same amount (from 18.0” to 17.0”).



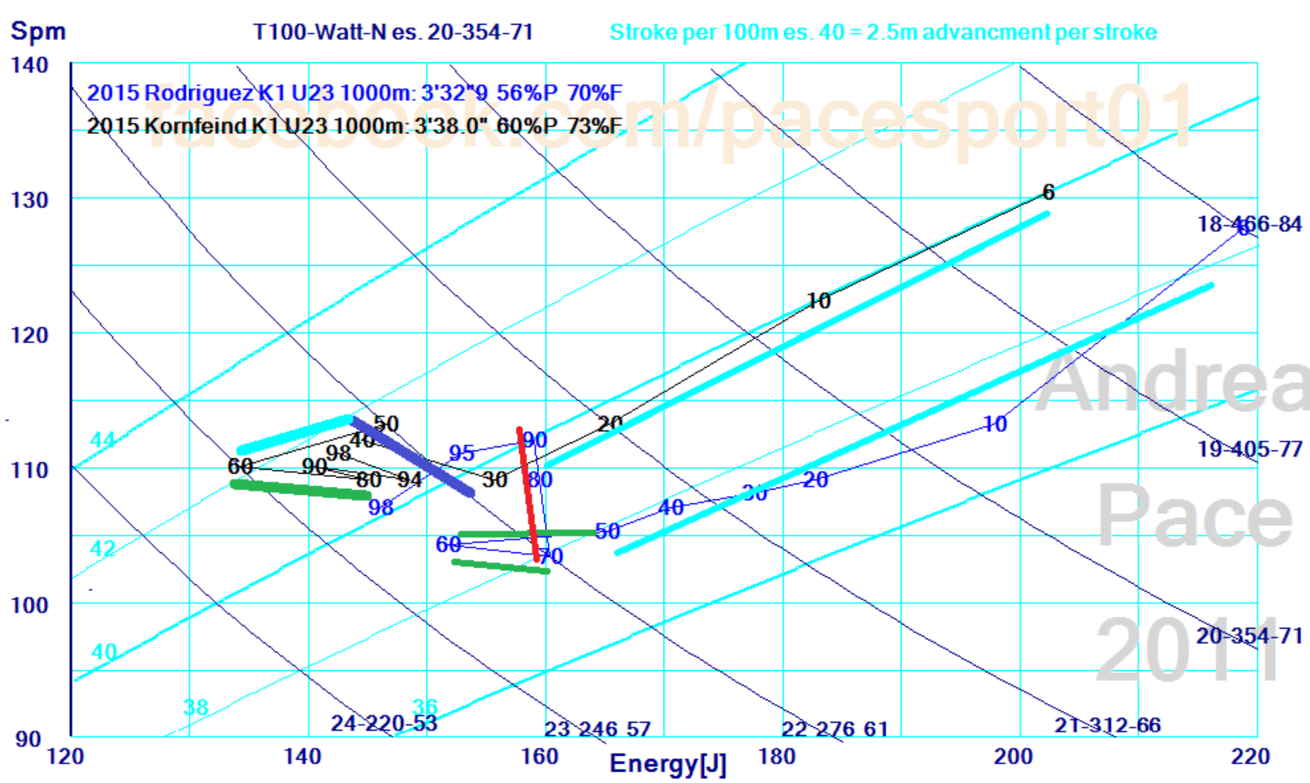
[Fig 3.2]

Chapter 4: The H-Graph

Kayak: Montemor 2015 K1 M U23 1000m FA

Fig. 4.1, below, shows the H-Graphs relating to the "K1 U23 Men 1000m | Montemor-O-Velho 2015" race (link: https://youtu.be/9i7o8Qdyogg?t=1m3s). Blue tags represent the first-placed athlete (ESP), and black tags represent the seventh-placed athlete (AUT).

The winning athlete follows a path similar to the one we have already examined, followed by M2x CRO, K4 AUS, and BLR. The athlete travels using a constant-advance mode up to the 500m mark (n100 = 37.5), and then proceeds to use a constant-stroke mode (105spm), slowing down up to the 600m line and speeding up again up to the 700m line. He then maintains constant energy per stroke (160 Joules) while simultaneously increasing frequency until reaching the advancement line with a value of n100 = 40, finishing the race with the same value of advancement.



[Fig 4.1]

Up to the 300m line, the AUT athlete travels using a constant-advance mode (n100 = 40). When he then falls to fourth place, he decides to try something. He travels at constant speed (blue line) between the 300m and 500m lines despite increasing the frequency by 5spm. He continues to lose ground to his opponents.

In **para. 6.1** we will have further occasion to examine the AUT athlete as a negative example for hydrodynamics. It must be said that, from the point of view of technique in relation to body movement, there appears to be no reason to think that he is a worse athlete than the winner: the root of the problem here are the athlete's brusque, abrupt motions. The desire to use all one's strength can have positive results on an ergometer, but not on a boat. At that speed, only 6.5kgf can be applied in a continuous way: using too much force before creating appropriate water support is counterproductive. By contrast, the rear blade of the oars of the M2x studied above actually smacks the water while submerging, in order not to lose ground. Indeed, at the end of each stroke they gain a few centimetres, instead of losing 12 like the AUT athlete does (see **fig. 6.1**).

Chapter 5: Definition of the Technical Aspects of Hydrodynamics

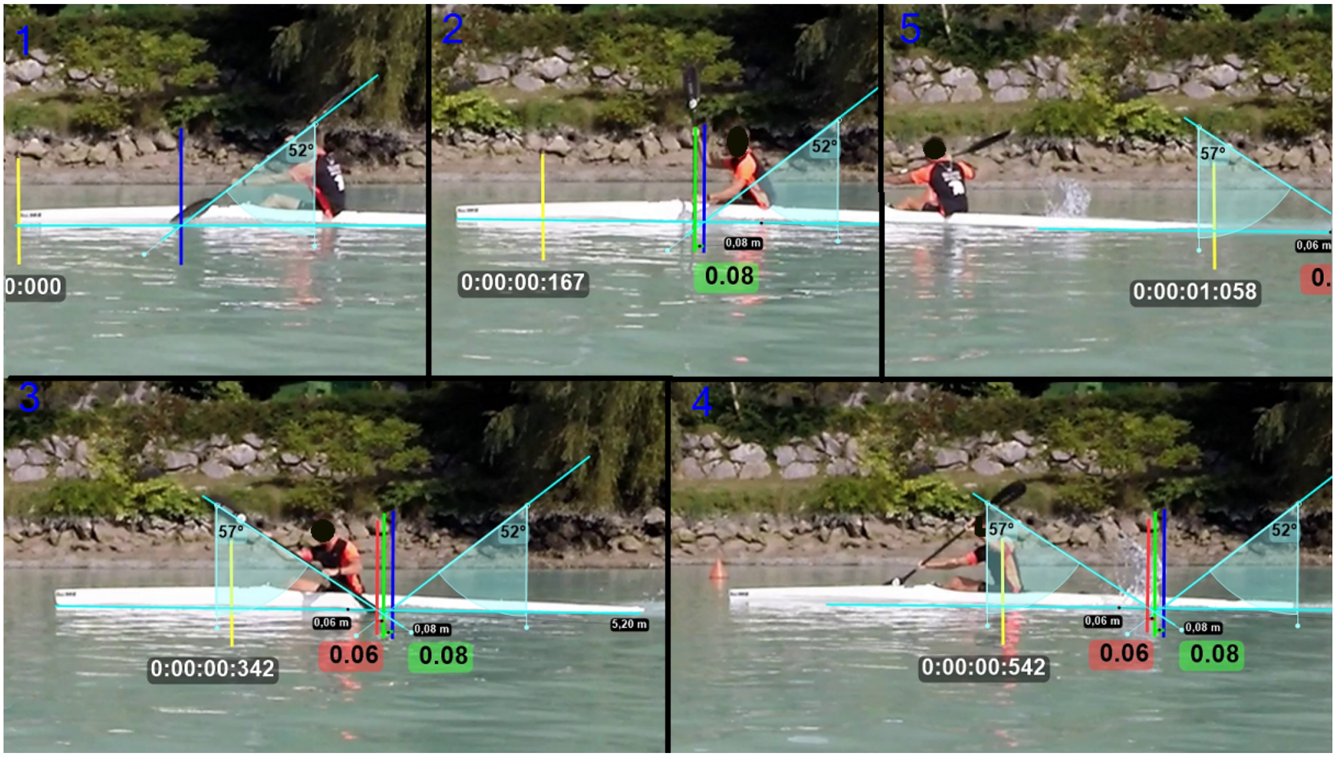
From the next chapter, I will be analysing athletes' technical issues in world cup Finals A. In the present chapter, I will define the method by which measurements are taken. We shall therefore be viewing several videos of athletes with the sole purpose of presenting methods for taking measurements.
C. Beltrami (*02) has previously studied and written about how certain video analyses deal with phenomena relating to space, while others deal with phenomena relating to time and the synchronicity between certain events.
The year 2015 saw the delineation of a series of measures called 'Step 1' (*04): this is a series of geometric measures carried out to track alterations in athletes' techniques.
Here, I will add some information regarding synchronicity or the sequence of events – for linguistic uniformity I shall call this 'Step 2'. Please note that the analysis shown in **fig. 5.2b** is further discussed in a different article (*03).

5.1 – Step 1: First Set of Geometric and Kinematic Measures

Fig. 5.1a shows how to collect data in five frames:
Frame 1 shows the *angle of entry*, obtained from the upper angle created by the paddle and a vertical line: this is the first result and it is equal to 52°. In the same frame there is a yellow line used to keep track of the kayak's journey time (5.2m). The point of entry of the paddle, obtained by crossing the cyan lines, is marked in blue. The cyan lines represent the extension of the paddle's handle, and the border between the surface of the water and the boat.
Frame 2 shows the distance of the paddle's shaft, traced with a green-coloured line as opposed to the previous blue one. Here we have a second result that is equal to a -0.08m slip in the first half of the paddle stroke.
Frame 3 shows:

1. The slip of the blade in relation to the reference point at the centre of the paddle stroke, traced by the vertical red line (similarly to what has been done with the blue line for entry); a -0.06m slip is added in the second half.
2. The exit angle, equal to 57°; and
3. The time spent in water, 0.342". ù

Frame 4 shows *stroke time*, which is equal to 0.542".
Frame 5 shows the time it takes for the kayak to travel 5.2m (or, rather, its own length): the boat tail crosses the yellow line at 1.058".
To achieve greater accuracy in the measurements, we can time 4 or more strokes. In order to measure angles we need a perfectly lateral camera angle, or a shot taken from a very long distance, or, simply, a video taken from a boat moving parallel to the kayak. Average speed will also be more accurate on distances greater than 5.2m.



[Fig 5.1a]

If a slow motion (x4) video is not available, calculate the average of the data taken before and after each event, i.e. entry and exit in water, and timings.

The measurements taken are:

Angle of entry = 52°
Angle of exit = 57°
Total angle (TotA) = 109°
Mid-stroke slip = -0.08m
Total stroke slip = -0.14m
Time in water = 0.342”
Stroke time = 0.542”

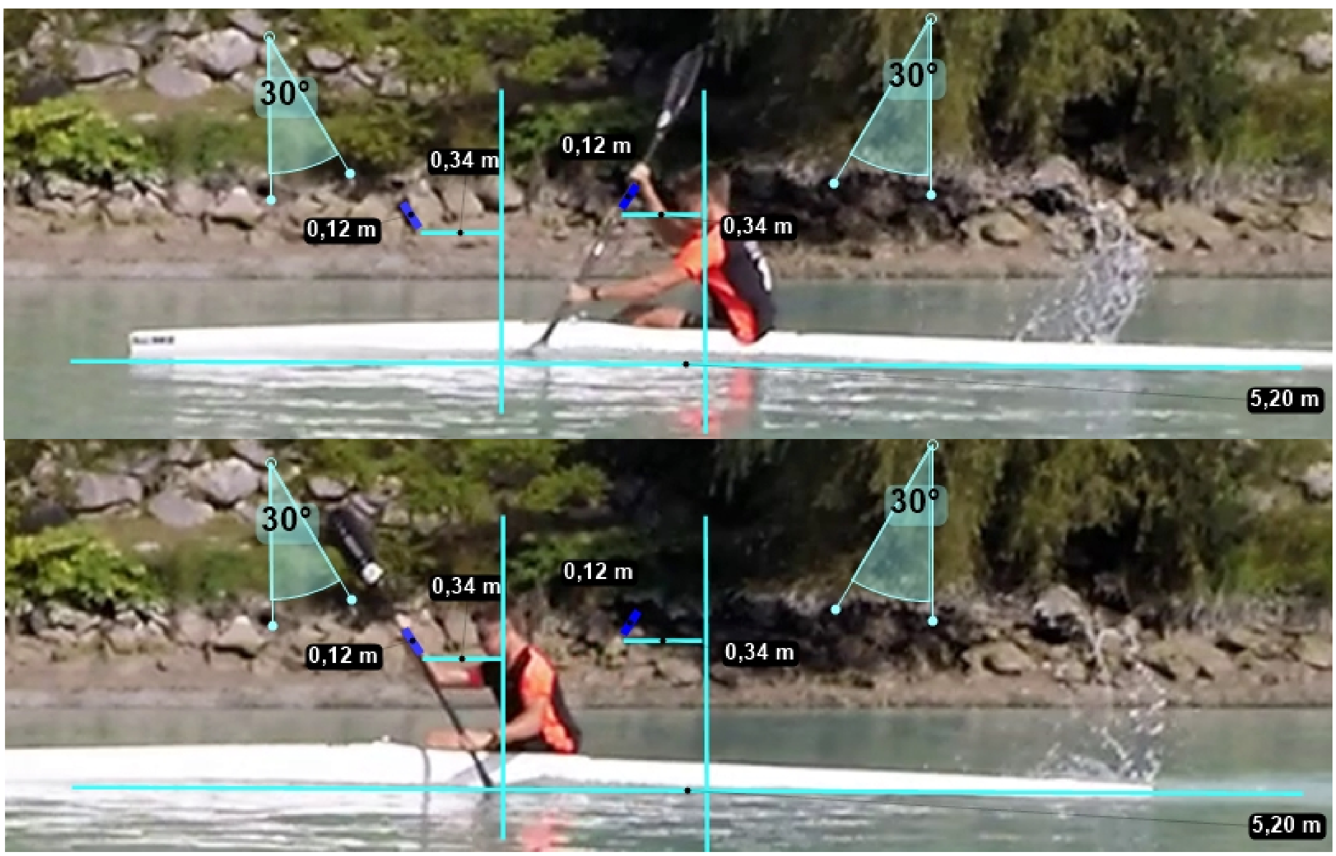
Once we have this data, we can use the software to obtain the calculated parameters, which are as follows:

%tWater (% of time in water) = 63%
%AirS/WatS (% air speed on water speed) = 111%
Stroke rate = 111spm
T100m (time per 100m) = 20.35%
Energy per stroke = 184 Joules
Energy per stroke (hard water) = 209 Joules
n100 (number of strokes per 100m) = 37.5
Advancement; advance per stroke = 2.66m
Stroke Radius 1 = 0.88

Apparent Radius 1 = 0.96
Average force per stroke = 69.2 N
Average force in water = 110 N

The following are the formulas used in the calculations:

%tWater = 100 x (time in water)/(stroke time)
%AirS/WatS = 100 x ((180-TotA) / TotA) x (%tWater/(100-%tWater))
T100 = 100 x Distance Time / Distance (e.g. distance = 5.2m)
Speed = 100 / T100 = 4.91m/s
Power = 5.393 x Speed^^2.6 = 5.393 x exp(speed, 2.6) (*) = 338 Watts
Energy per stroke = Power x 60 / Stroke rate
n100 = Stroke rate x T100 / 60
Advancement = 100 / n100
Displacement = Time in water x 100 / T100
Average force per stroke = Power / Speed
The Radius formula will be given below.



[Fig. 5.1b/c]

(*) Two coefficients have been used to calculate power. The coefficients are calculated as follows:

1. The speed exponent, 2.6, has been calculated by successive approximation using hundreds of tests conducted by Oreste Perri between 1991 and 1996;
2. The coefficient 5.393 I have calculated myself in order to homogenise race results with results obtained on a kayak ergometer. It has been verified both on athletes belonging to the national team and lower-level athletes. In both cases, all the appropriate corrections for athlete weight have been carried out, reaching a standard weight of 80kg. With regards to the measurements carried out on boats, in the majority of cases there is no need to correct the athlete's weight. What one must keep in mind is that, on an H-Graph, when we see a figure of 70N for an athlete weighing 60kg, the real force applied is actually lower.

Fig. 5.1b/c shows a geometric method to obtain information on **Radius1**. Through trial and error, one must try and find the point on the shaft that is equidistant from the body when the paddle is at approximately 30°. In the present case, the point that is equidistant from the athlete's body is located 0.12m from the upper-placed hand, and 0.34m from the vertical line that crosses the ear. In reality, the 0.12m figure is an underestimation of the real figure since the paddle is tilted. Anyway, it is easy to spot that the shaft's rotational point is closer to the upper-placed hand rather than the lower-placed one, and that the Radius is therefore higher than a neutral position with the origin of the Radius placed at the centre of the paddle itself.

The calculation of Radius1 comes from the simulation of a wheel spinning on the surface of the water with the following characteristics: it spins with the same angular speed as the paddle and it travels the same distance as the boat during the active stage. To verify this mathematically, in our case we have a speed equal to 100/20.35 = 4.91m/s; during traction in water the displacement is equal to 0.342 * 4.91 = 1.68m; a wheel travelling 1.68m spinning TotA = 109° must have a **Radius1 = 1.68 x 180 / (109 x 3.14) = 0.88m**.

If we watch video footage of a kayaker shot from a lateral point of view, we will be able to see that upon entry the upper-placed hand (i.e. the hand that pushes) may behave as follows:

1. Remain at the same distance from the body until completion of the stroke (maximum Radius1);
2. The point on the paddle's shaft that remains at the same distance from the body is located in proximity of the upper-placed hand (elevated Radius1);
3. The point on the paddle's shaft that remains at the same distance from the body is the shaft's middle point (short Radius1).

Geometrically speaking, there are several ways in which we can obtain a greater Radius. We must choose one that corresponds to a precise technique, or we risk improving the Radius but damaging all the rest.

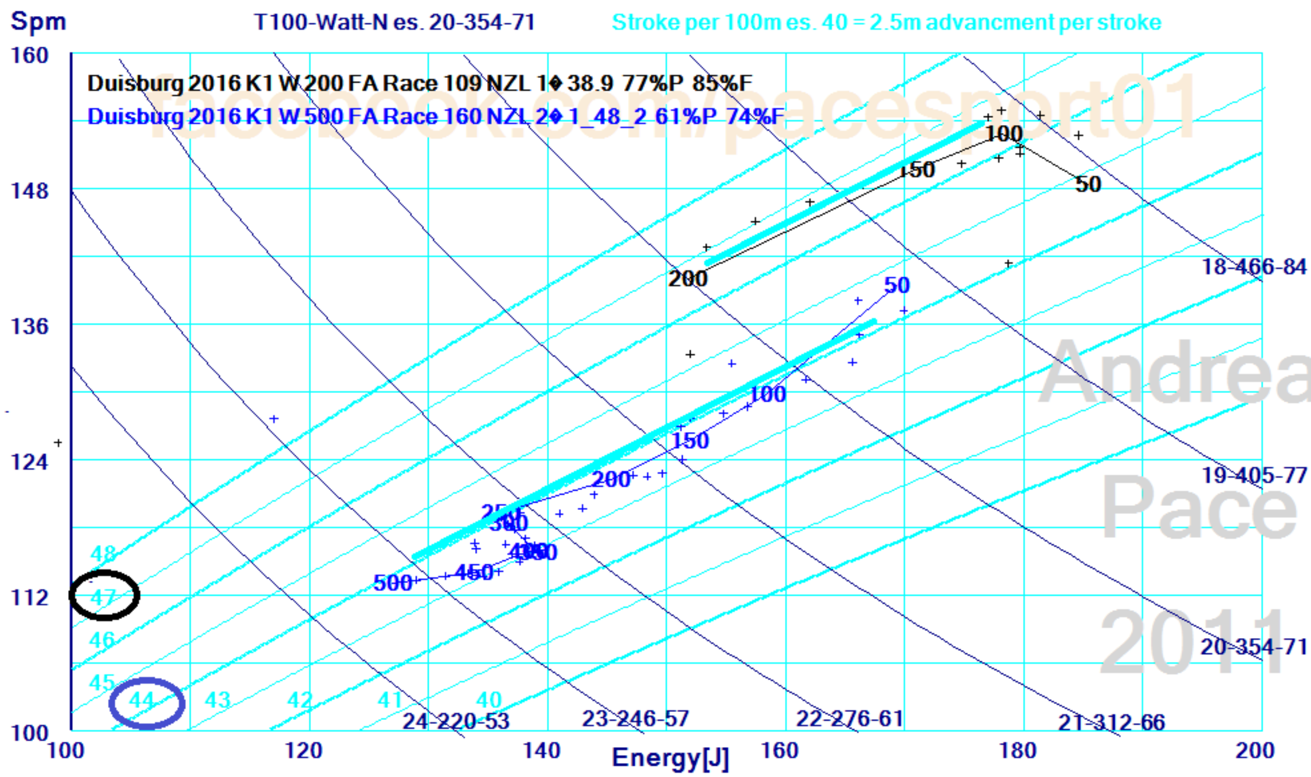
From the point of view of physics, a Radius1 variation has a relationship with the water mass affected equal to the Radius1 itself to the power of 4. In practice, this means that increasing Radius1 by, for instance, 10% (equivalent to shifting from 1m to 1.1m), causes the amount of water mass affected to increase by 1.1^4, or 1.1 x 1.1 x 1.1 x 1.1 = 1.46. This means that, for a 10% variation in Radius1, there is a 46% increase of water mass affected. A larger mass of water means steadier support, which is

always advantageous from the point of view of effectiveness. In order to take advantage of the hydrodynamic power, however, one must also have a large angular sector, between 90° and 110°: it is no coincidence that these figures are similar to those on use on rowing boats. Increasing Radius1 and the angular sector leads to an increase in advance per stroke and, consequently, a lower stroke rate. This explains why many trainers tend to prioritise increasing advancement or energy per stroke. However, as we have seen in **Chapter 1**, winning athletes often have small advancements, signifying that there are other important physical phenomena at play in defining the objectives of technique, namely, the elements of Meta-Technique.
From a dynamic point of view, the value of Radius1 can differ from the geometric value for a number of reasons: the paddling motion is not perfectly circular, therefore the Radius's dynamic effect changes with each translation linked to the rotation itself. The most important translation is that which modifies the paddle stroke's trajectory in the first part of the motion, and that is carried out precisely to create the steadiest possible support for the whole traction.

Unfortunately, the figures of the Radius and angular sector are limited by the athletes' abilities; we cannot change these figures at will. Obviously, we will expect both the Radius and angular sector pertaining to an athlete who travels 1000m at 120spm to be lower than that of an athlete who travels the same distance at 100spm (at the same speed). This happens because, usually, the %tWater is constant: if we accept a reduction of the %tWater an athlete can increase the advance per stroke and lower his stroke rate - while maintaining the same speed - simply by increasing the aerial stage. As a consequence, the athlete will have to apply greater average force in water, the implications of which can be found at **para. 8.2**.
On this topic, looking back at the H-Graph pictured in **fig. 4.1**, we can see that Rodriguez proceeds along the constant-advance segments first with a value n100 = 38, and later with a value n100 = 40, with angular sector measurements of 110° and 100° respectively.
This shows how, in a 1000m race, Rodriguez is able to follow his chosen technique while at the same time leaving some scope for the adjustment of those parameters that he is capable of regulating. Along these segments, his objective remains that of achieving the highest level of hydrodynamic efficiency that his technical capabilities and available energy allow.
In the last 250m of the same race, the Australian athlete Bain increases stroke rate and speed and reduces Radius1. He comes in 2nd, beautifully carrying out his race tactics. This proves that there is no hard-and-fast rule regarding how to modify paddle stroke parameters during the race: the athlete can only reduce those parameters that slightly exceed the requirements of good hydrodynamic efficiency.

In any water sports race (swimming, rowing, kayak), when the same athlete or crew runs a short race, they do so with a lower advancement rate compared to that of a longer race. Please refer to the case study shown in **fig. 5.1d**: Lisa Carrington (NZL), proceeds with a value n100 = 47 in the 200m race (marked in black), and with a value n100 = 44 in the 500m race (marked in blue). The same thing happens in Rodriguez's race (Fig. 4.1), when he goes from n100 = 38 to n100 = 40.
This also occurred in swimming races with champions like Cielo (50m and 100 freestyle) and Phelps (100m and 200m butterfly stroke) (*01). Even in swimming we can see the phenomenon of reduction of advancement in the final stage of races. For instance, athletes with a 2.15m advancement per cycle in

a 50m, race will change their behaviour as follows in case of a 100m race: in the first 50m their advancement is equal to 2.40m, and in the second 50m it is equal to 2.15m – same as in the 50m race.



[Fig. 5.1d]

We can conclude that athletes use a reduced advancement in the following cases:

1. In faster races that require increased strength;
2. In the same race and at the same speed, but at that moment when they are left with a lower level of strength, of which they can only avail themselves by making use of levers in order to lighten the load on certain muscle groups, or by finding increased strength in a more efficient angular positioning of the joints.

As mentioned above, the reduction in the %tWater causes an increase of the average force that must be applied in water. In a race, this represents a great disadvantage and, as a consequence, we do not see many athletes with a %tWater lower than 60%. This reduction, however, is one of the ways to train strength. We will see that it is part of that category of training methods that is only beneficial to near-perfect athletes. Even a large number of athletes participating in Finals A world cups are far from being skilled enough for this type of exercise: essentially, we run the risk of training and stabilising the athletes' ability to make mistakes (**Chapter 8**).
Fundamentally, it is not important if the boat proceeds with a marked pitch motion (as we shall see in the Hungarian athlete Kozak's case study): what matters is that the hydrodynamic elements carried out are the correct ones (namely, pitch harmony and absence of turbulence near the blade, meaning zero or negative slip).

Going back to the increase of water power produced by the lengthening of the aerial stage, if we watch the various videos available on YouTube featuring the M2x CRO crew we can see that they make use of this type of mode. Going at the same speed and using the same stroke rate as the M2x CRO crew is not enough: it can be done in far too many ways, and only one way is the right one. In order to avoid having to carry out potentially hundreds of attempts at finding the right one, we can see from the following videos that:

1. The average force applied in water has the same value for all the stroke rates;
2. The water slip must be equal to zero (or negative) both at 20spm and at 45spm, and therefore the preparation for the entry phase and for the final phase must not be conducted brusquely or hurriedly;
3. The angular sector must be the same both in the exertion of strength and other modes. As a consequence, the oars stay up in the air proportionately longer as stroke rate decreases;
4. In rowing, the value of Radius1 is virtually fixed (it can loosely be considered as the external lever), while with regards to kayak, on the other hand, it is to be taken into consideration.

If these conditions are met, the average force in water at both 20spm and 45spm is exactly the same. This leads many trainers to take advantage of lower stroke rates when carrying out strength training in water, since a lower rate means the athlete does not get as tired and the strength training can go on for longer without causing any significant oxygen shortage. In **Chapter 8** we shall see how this system can become dangerous when the four above conditions are not met. In this case, it would be better to carry out strength training in water using appropriately engineered hydrodynamic brakes (**para. 8.2**).
In kayak it is also important to fully understand a further phenomenon. Going back to the K4 crew shown in **fig. 3.2**, we can see how at 300m the crew has a value T100 = 18”, a stroke rate of 120spm, a value n100 = 36, and energy per stroke equal to 235 Joules. Strength training in water with equal speed at a rate of 100spm may be taken into consideration, but, if the goal is to achieve K4 BLR’s n100 = 33, we must swap the water training with technical training.

The following are some hypothetical calculations:
Supposing that in the race K4 ITA’s %tWater figure is 65%, and that at 120spm the blade is in the water for 0.325” and in the air for 0.175”, if we proceed at the same speed but with a frequency of 100spm, the blade will be in the water for 0.325” (since we are assuming that technique remains unchanged), however, since the stroke time goes from 0.5” to 0.6”, the blade will be in the air for 0.275” and the %tWater becomes 54%. In this case, the average force applied in the active stage (which in the first case was 84/0.65 = 129N) will be 84/0.54 = 155N.

The reason why we must try to maintain a high %tWater is because the most constraining factor in the race is, indeed, the application of force. Having to apply an extra 155-129=26N for purposes of acceleration (i.e., that amount of force that cannot be immediately transferred to the boat since the boat requires 84N non-stop), is something that can only result in success for a small fraction of the race.

Therefore, for K4 ITA to eventually reach the same level as K4 BLR, they must simply increase the

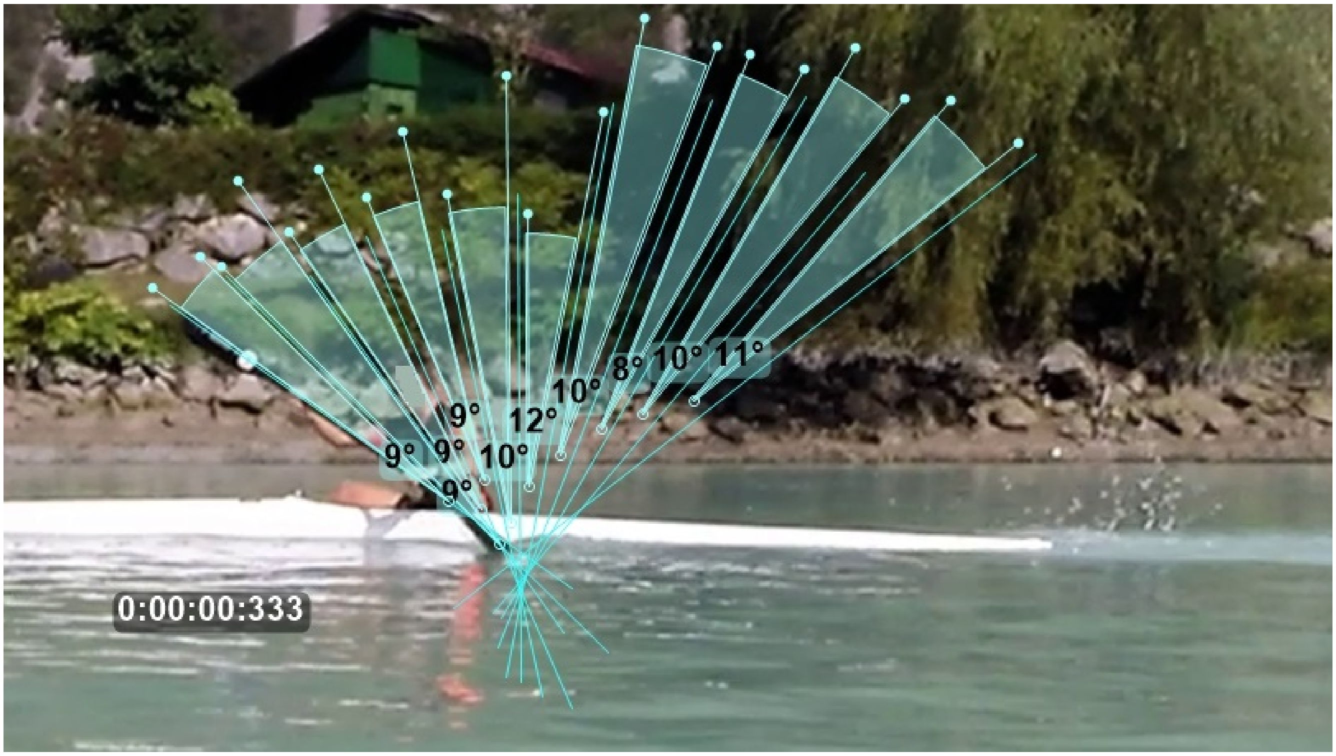
angular sector and Radius (unless these parameters have already reached the limit beyond which efficiency actually declines). As we have seen, since the force applied in water as a consequence of the increased time spent in the aerial stage is nothing more than a force of acceleration (**para. 8.2**) that cannot be transferred to the boat (in fact only a very small part can be), *it is incorrect to perform strength training by reducing stroke rate*, and instead training must be carried out using a hydrodynamic brake that will restore the correct relationship between pulling forces and forces of acceleration (as calculated at *para. 8.2*), or else the force will be exerted with inefficient technique (unsuitable Radius and angular sector), and with a relationship between acceleration and pulling force which is not easy to deal with, especially for athletes/crews already experiencing problems with other aspects of Meta-Technique.
As we have seen in the race pictured in **fig. 4.1**, the athlete (Rodriguez) changes only the angular sector's value, taking it from 110° to 100° (or at least this is what can be discerned from the video, which is not well-suited to technical analysis). Ideally, we as trainers would analyse each athlete's changes in the Step 1 parameters at the various stages of the race during which the athlete proceeds at the same speed but with different stroke rates.

5.2 – Step 2: Second Set of Measures

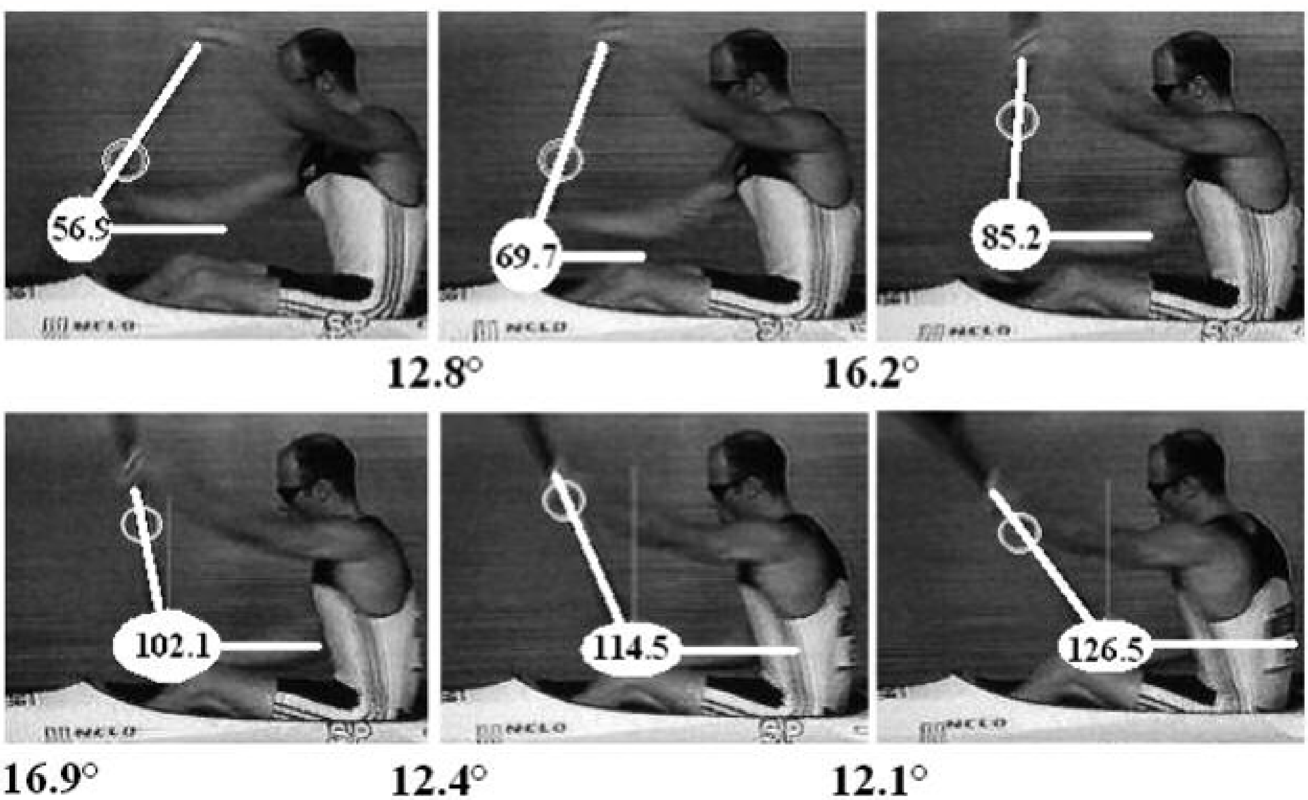
Whereas the first set of measures aims to assess technique by means of geometric characteristics and speed, the second set focuses on data like time and synchronicity.
Please keep in mind that physical phenomena such as forces and inertias cannot be measured directly from a video; should an error occur, however, the effects on the motion of the boat, paddles and oars will be amplified proportionally to the relationship between the athlete's weight compared to the weight of the boat. The paddle's sound is also important – in order to assess it, we must observe the athletes while the engines are switched off.

5.2.1 – Measuring the paddle's angular variation from a lateral point of view

Fig. 5.2.1, below, shows the angle created by the paddle's shaft for each frame (at 30fps). The data shows some anomalies: a quick entry (11°/0.033", then 10°/0.033"), some slowing down (8°/0.033"), then again some speeding up, and a slow finale. In the next chapters, we will study the behaviour of some champions.
A rapid change of a paddle's angular speed is a warning sign of major problems at certain stages of traction; in this case, around one quarter of the way through traction. However, in order to determine the dynamic root of this type of anomalous angular behaviour, we must look at what happens during the critical stages from different points of view, as we will do at **para. 5.3**.
The shot can be also taken by a camera moving next to the kayak, as long as the shot it perfectly centred. Also, using an optical zoom, the further away the camera is from the kayak, the better.
Fig. 5.2.2 shows Larsen during the K1 1000m Finals A of the Athens 2004 Summer Olympics (*03). In this case, the data shows no abnormalities, but they do show a faster segment in the middle (16.9° / frame).



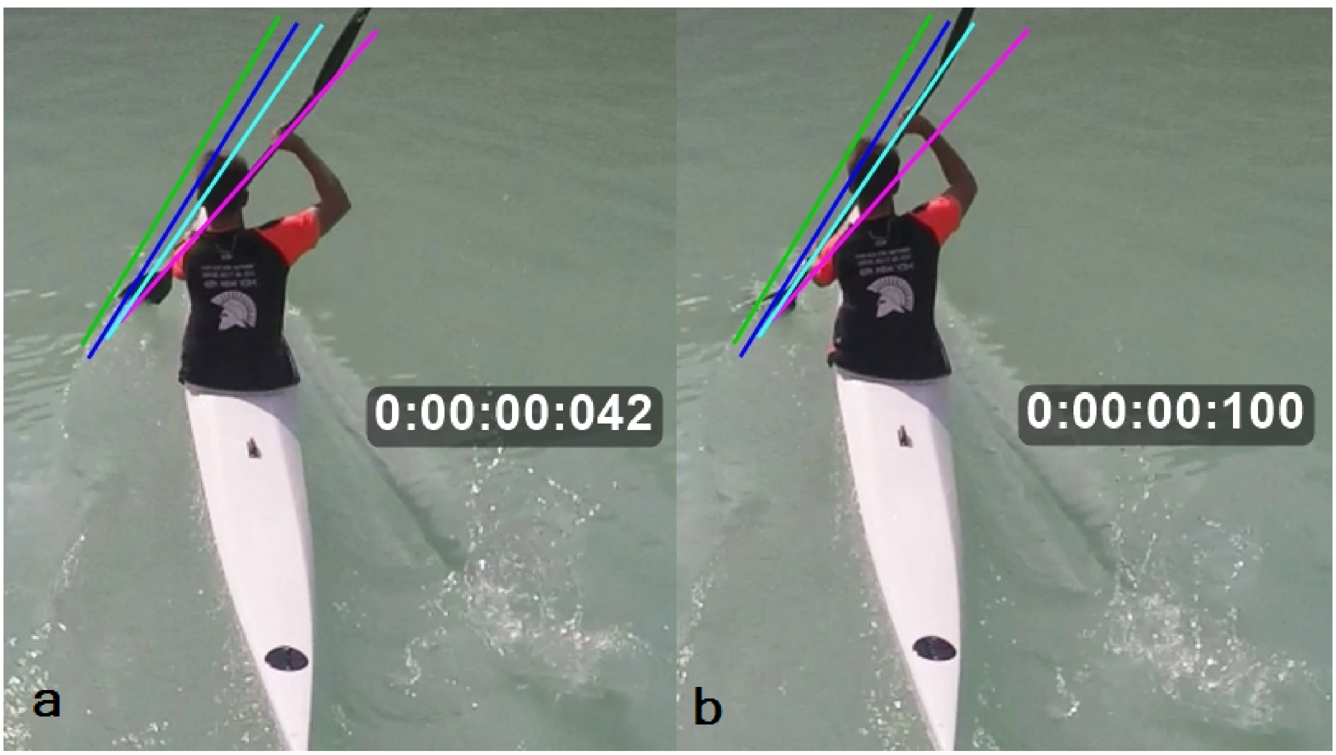
[Fig. 5.2.1]



[Fig. 5.2.2]

5.3 – Measuring the paddle's angular variation from the rear

The image shown in **fig. 5.3** is not a perfect rear view, and this will cause an alteration in the angles' measurements. What matters, however, is that every qualitative analysis helps us achieve the intended purpose – in this case, the topic picked up at **para. 5.2**.
From the rear view, the paddle's angle should not change (except possibly in the first hundredths of a second during entry, when the blade is partially submerged). **Fig. 5.3**, however, shows a variation precisely at the angular anomaly seen in **fig. 5.2.1**. The issue here is that this angular variation is greatly delayed with respect to the transitional entry stage: at this stage, only the strongest muscular group should be active, and therefore the arms should only transmit force and not alter the trajectory and, as a consequence, the whole inertial equilibrium.



[Fig. 5.3]

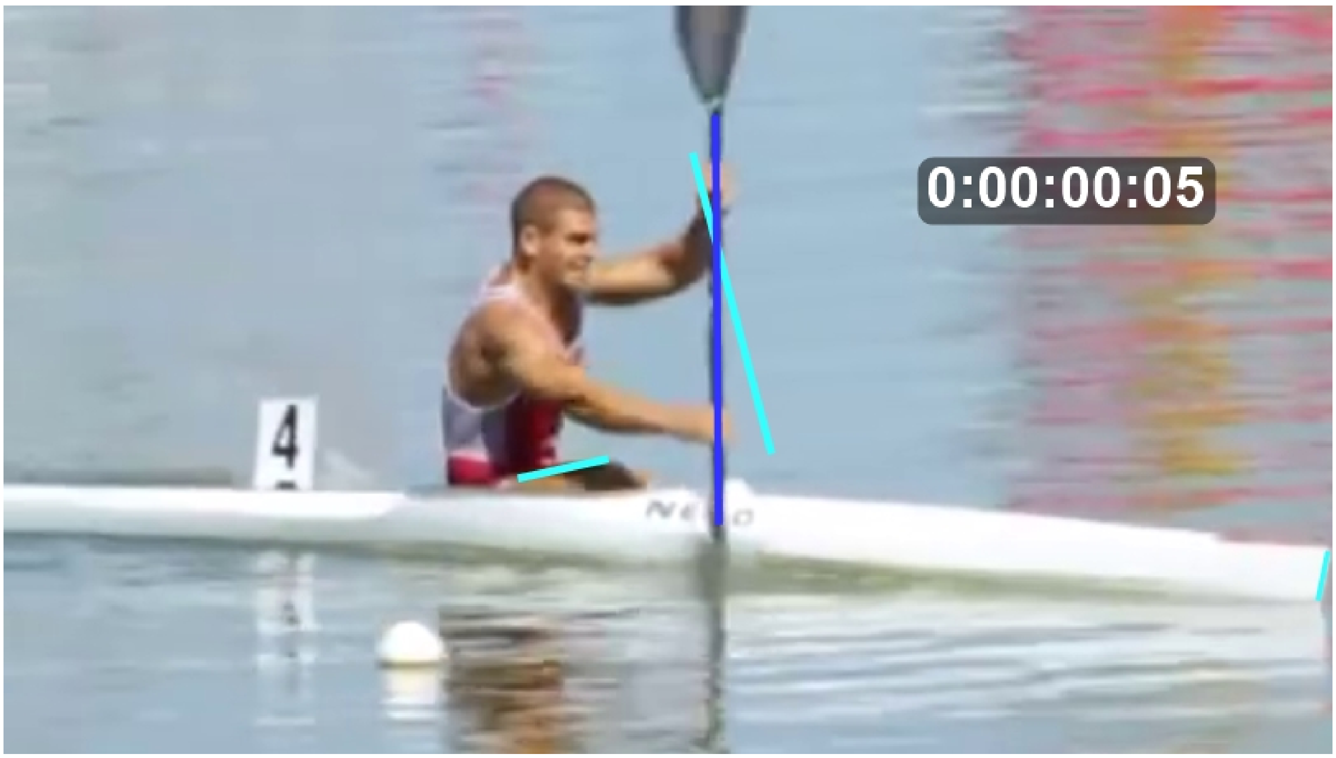
Fig. 5.3a shows the action 0.042" after initial contact with the water: the bright pink line highlights the paddle's position; the upper-placed hand moves further away from the boat compared to the hand exercising traction.

Fig. 5.3b shows the action at exactly 0.100" – the paddle is shown with a cyan line. From this moment, there is no significant change in the inclination.

5.4 – Measuring entry; kayak and rowing; variation of pitch angle

A blade entering the water can be very interesting to observe. Kayak athletes want the motion to originate from the legs, in order to transfer strength to the upper body as quickly as possible. Physics tells us that this is impossible.

For purposes of efficiency, in situations where there is a collision – like in water sports, where there is always a collision between water and athlete/equipment – the interacting masses must be equal. During the blade's submersion stage, for a few hundredths of a second, the interacting water mass is small, and athletes must apply force using a mass of the same size. Athletes should therefore use only the arms/shoulder blades, for the purposes of starting the motion as quickly – and yet as gradually – as possible, or they must accept the brusque impact that is the result of the motions of stiffer athletes.



[Fig. 5.4a]

The cyan lines in **fig. 5.4a** show the position of the paddle's shaft and the athlete's legs at the precise moment when the paddle comes into contact with the water. The blue line shows the position of the paddle's shaft 0.05" later. We can see the paddle is now submerged; propulsion has begun; the pushing motion against the footrest has indubitably been in place since before entering the water (since, in kayak, the boat's braking force can be countered by the legs even in the aerial stage); the right knee has still not been lowered, and the other knee has already moved in the opposite direction. The athlete pictured is Marko Tomicevic, in the Szeged 2011 K1 (as seen in the slow-motion 60fps YouTube clip titled *Slow 2 The Ultimative Canoe SloMo Paddling Video [Szeged 2011]*).

Fig. 5.4b shows the Sinkovic Brothers' crew as seen in the YouTube clip titled *Braća Sinković na Peruči i Rami 2015*. As above, the cyan lines show the position of the paddle's shaft and the athlete's leg at the moment of collision between paddle and water. After 0.08" the oar (blue-coloured) is half-submerged, and the legs (also blue-coloured) maintain the same tilt as they did in the beginning (the same happens with the tilt of the back, but no coloured segments have been included to show this in order to avoid confusion.)

The difference between kayak and rowing is that in the latter, at this stage, no force is applied in water at least until the oars are not almost fully submerged. In rowing, athletes face the opposite way compared to kayaking, and as a consequence the boat's brake force in the aerial stage is not countered by the soles of the feet by the upper part of the feet. Part of the brake force is also countered by the mobile cart, since the guides tilt slightly downwards to the boat tail; this tilt is added to the boat's own tilt. Entry will be easier if the athletes reverse the push of their feet from the upper part to the lower part at the right moment: in this way, they can begin the active action without moving their bodies away from the boat before the oars have achieved optimal water grip.

In **fig. 5.4a** we see a method for entering water that is surely efficient since it has been taken from a 1000m race, which is a race long enough for efficiency to become the main problem.
Fig. 5.4c shows the athlete Marko Dragosavljevic (SRB) in the 2013 Montemor o Velho K1 200m Men European Canoe Sprint Championships
The following is a summary of the kayak blade's entry in water. We have two simultaneous stages featuring the hand exercising traction and the leg exercising traction. These two actions have different purposes: the movement that starts from the hand and from the shoulder blades only lasts a few hundredths of a second and serves to interact with the water until the water mass is large enough to sustain the impact of the rest of the athlete's body. The movement coming from below anticipates both the opposite leg's push and the contact with water so as to preload and fix the torso's rotatores muscles in relation to the pelvis. Before entry there is usually no rotational movement of the torso: if this happens it will be damaging to athletes who will be unable to finish in the top positions.

Fig. 5.4c shows a further difference compared to **fig. 5.4a**: the preloading movement between the torso and the pelvis is more significant and affects both the leg exercising traction and the pushing leg, already three frames before contact with water. This corresponds to a lower degree of stiffness in the transmission between torso and pelvis. The athlete pictured is in fact less stiff also from the point of view of muscular contraction, and this could be the reason why he excels in the 200m race, except at the very beginning, when stiffer athletes with a simpler synchronicity always prevail.

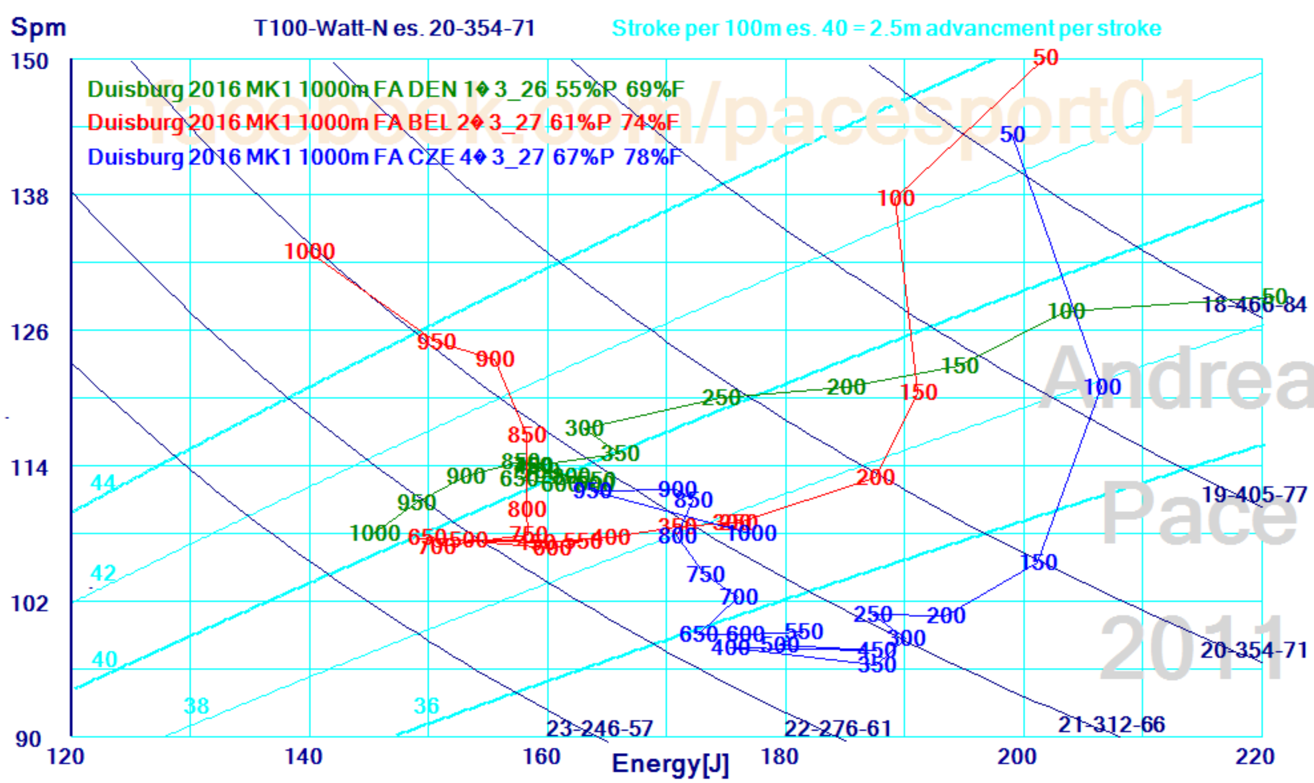
This way, the athlete obtains a different trajectory (one that is closer to the boat), and, in the final stages, the flexibly preloaded muscles give him steady support. However, we cannot say whether this is the most fruitful method.

[Fig. 5.4b]

[Fig. 5.4c]

In 2013, this athlete stands out due to the high Radius1 value and the neutral position of his torso, which does not move with respect to the boat. Moreover, his body's flexible movements (core muscles) have low initial stiffness values that allow him to avoid collisions with water at the entry stage. Trying to anticipate the leg movement or, on the other hand, carrying it out at the moment of entry, leads to an excessive amount of inertia compared to the water's inertia (precisely because we must wait for the activation of 'water grip', and the flexible preloading of the paddle). Additional dispersive phenomena can be noticed, i.e., regression and water turbulence.

The variation of pitch angle is a phenomenon that must be considered case-by-case, as it differs greatly from athlete to athlete. The ideal pitch motion is a harmonious, with the boat nose and tail having equivalent vertical speeds, and with equivalent duration of the upward and downward stages, just like a dolphin. Athletes who end the stroke by pulling their bodies back and pushing the water upwards produce a pitch motion in which the boat's 'rising' stage lasts longer than the 'dropping' stage: this causes a downward jolting motion that often submerges the boat tail and causes a delay in the athlete's action. When next entering the water, the athlete will not be in phase with his own body's, and the boat's, oscillation (indeed, the 'right moment' painstakingly sought after in rowing) and all the conditions will be so set for a further deterioration of the situation.
The situation described above is similar to what happened to athlete Dostal (CZE). In order to wait for the moment when it would have been possible to perform the subsequent entry in water, his %tWater = 60%, as opposed to the more efficient value of 65%. Furthermore, as his speed increases he regresses further to the point where he is forced to reduce stroke rate.



[Fig 5.4d]

Fig. 5.4d, below, shows the H-Graph of the Duisburg 2016 World Cup. Dostal, shown in blue, is clearly visible due to the fact that, between 950m and 1000m he increases speed while reducing stroke rate: he finishes the race in fourth place. The BEL athlete, shown in red, finishes in 2nd place, using a constant-speed mode. From 850m to 1000m he maintains speed equal to T100 = 21.0", increasing stroke rate from 116spm to 132spm: he therefore has a lot of reserve energy in the final stages of the race, but he is unable to take advantage of this. The DEN athlete (Poulsen) wins the race by systematically following the most efficient mode: he proceeds along the whole track at a constant advance per stroke rate equal to n100 = 40.

5.5 – Measuring the body's advancement in the final stages of the paddle stroke. Radius2 Modulation; Extra-pull

Radius1 is relevant from a geometric and dynamic point of view, and it is fundamental for the purposes of defining advance per stroke and the water mass with which the blade interacts.

Radius2 is approximately equal to the distance between the blade in water and the kayak's central longitudinal axis. Radius2 increases steadily from the moment the blade touches the water to the moment it leaves it: this happens when the tilt of the shaft (from a front or rear point of view) remains unchanged during the active stage. In **figures 0.7** and **5.6** Radius2 is shown with horizontal red lines.

Along with Radius1, Radius2 is also geometrically and dynamically relevant:

1. Geometrically, because as Radius2 increases, advancement per stroke also increases; and
2. Dynamically, because it is the lever which balances all the inertias of both body and boat with water inertia. To be more specific, as Radius2 increases, the mass represented by the body relative to the 'centre' of the submerged blade decreases quadratically. This means that increasing Radius2 by 100% causes a reduction of the equivalent body mass equal to 400%.

When discussing the various examples of technical training considered in the present paper, I will make use of the term 'modulation'. What is meant by this term is the variation of a 'parameter' with the aim of perfecting an element pointed out by the trainer. In the following example, the parameter is Radius2, and the aim (i.e., the element of Meta-Technique that must be optimised) is the balance of inertias: the visible effect of this can be found in the variation of rotational speed, the possible slip of the blade in the water, and in the interruption of the action after the blade has left the water (regression).

Two things may happen when doing K1 training with the aim of learning Radius2 'modulation':

1. If, halfway through traction, the athlete suspends the action of moving the blade away from the boat, this will cause an excessive lightening of the pressure put on the blade, and the higher the angular speed of the body, the stronger this effect will be;
2. If the body has low angular speed, opting for a high Radius2 with a view to further increasing it may cause an additional reduction in rotational speed, with the risk of being left unable to complete both the body's and the stroke's angular sector.

We have seen that the balance of forces and inertias in the active stage is very complicated. Assessing the radii, being aware of the fact that they are linked to the two inertias (that must be themselves balanced), and knowing that a 1cm variation is enough to make a significant difference, is already a big step in the right direction.

Since the body's equivalent mass depends largely on the athlete's weight and body shape, each athlete will have to select the right, tailor-made combination of Radius1 and Radius2. For a crew this can be a great problem: in this case, we must first obtain the right balance between the two radii, altering both the size of the paddle and the grip on the paddle; the paddle's stiffness will also be a decisive factor. It goes beyond the scope of this paper to explain how the balancing of radii occurs by means of the variation of the three elements mentioned above, however, in brief, I must mention that the best way to go about it is to alter one element at a time. An example of this would be modifying Radius2 while maintaining Radius1 unchanged. Suppose that, in order to optimise the elements of Meta-Technique, an athlete has no choice but to increase Radius 2: we can repeat the process for each element relating to each crew, one by one. The equalising of angular sectors must be dealt with at a later point, with a different Radius 1 figure. Even the height of the seat increases Radius1, and it is a further element crews can use to avoid individual crewmembers having different angular sectors.
Let us now consider Finals A 500m and 1000m athletes. Athletes who proceed at a higher stroke rate compared to their opponents have a shorter Radius1; because their paddle stroke is usually not very vertical, they also have a high Radius2. Athletes with these characteristics are Osipenko in K1 W 200m and 500m and Poulsen in K1 M 1000m. For the reasons of balance of inertias mentioned above, this combination is the right one, since a small Radius1 reduces water inertia and a high Radius2 reduces the body's equivalent mass, and, therefore, the equilibrium is appropriately reached. It is not, however, the best solution from the point of view of efficiency.

Reducing Radius1 signifies interacting with a smaller amount of water inertia. Athletes must therefore perform lift movements when paddling to avoid water slip. The lift movements are performed by allowing the water to flow on both sides of the blade at an angle that is close to the geometric tangent to the two sides of the blade (**para. 0.5**) (*06). In this way, it becomes very hard to aim for maximum efficiency since the blade is subjected to a disproportionate amount of water friction.
Athletes who find themselves in trouble can lighten the load on the paddle stroke by reducing the angle created by the traction arm and the torso (in **fig. 5.6** the centre of this angle is 116°). This may actually be a mistake: Radius2 is basically the lever by which the athlete and boat inertias (especially the body's flywheel effect) are balanced with the water inertia present around the blade. This happens by means of the paddle and, therefore, reducing the lever of resistance (Radius2) even by just a small amount has the same effect as if the athlete's inertia increased, and the contrast with the water creates a slip. As a consequence, the rotation does not slow down or speed up, but only on the traction side, and there is a regression effect on the body: this phenomenon is as difficult to explain in writing as it is easy to observe even on mid-level athletes, and it is a way to *disperse energy in cases of internal friction (intro-push)*. Consequently, if one trains for this, it will be possible to 'modulate' Radius2 so as to reach the correct rotational speed.

Ideally, if we make perfect use of both Radius1 and Radius2 the stroke will end in a situation of virtual neutrality, with minimal forward acceleration of the body compared to the boat. At the same time the

boat must have no negative acceleration if not that which occurs naturally due to the water's hydrodynamic resistance. In K1 there are only a few examples of this optimal behaviour: for instance Adam Van Koverden in the K1 1000m 2011 World Championship final, and, though inferior to Van Koverden, Bain (Australia) is also worthy of mention as he does something similar (we can see him in lane no. 8 in **fig. 6.1c** during the World Championship U23 2015 K1 1000m Finals A). Poulsen cannot be used as an example since, although his action is centred and harmonious, his Radius1 value is one of the lowest, and therefore his race behaviour cannot be seen as a reference point worthy of being replicated.
The images below will show that winning athletes use the body's rotational energy when exiting the water for the purpose of bringing themselves forward compared to the boat without, however, slowing down the latter by causing it to be subjected to a brake force. This is called extra-pull because, contrarily to intra-push, part of the wasted energy is recovered and redirected in the right way forward; outwards. If the movement is perfect, despite there being, in the final part of the stroke, a reduction in the value of Radius1, it will be greatly efficient.
In kayak this is supported by the fact that Radius2 is always increasing, and thus facilitates the exchange of rotational impulse between body and water.
In rowing, the same physical phenomenon is used to optimise the exit stage: without going too much into detail, we can see that the action is supported by two elements which are very similar to Radius2 and to the management of the body's rotational inertia, both of which are increasing:

1. The fact that the oarlock movement alters the relationship between levers so as to progressively favour the internal lever rather than the external one;
2. The fact that the torso's extension greatly increases the body's rotational inertia (from an engineering point of view, this is the moment of inertia);
3. These physical phenomena allow athletes to perform the desired movement with maximum efficiency. Having more or less strength and water grip at the end of traction is a consequence of energy optimisation, rather than an action that we can arbitrarily ask athletes to perform. If we do so, the athlete, whose movement is already too fast due to an incorrect water grip, will probably attempt to apply more force thus making the situation worse.

This sort of forward 'leap' is the element that requires the most awareness, and it is substantially the starting point of the whole stroke: this is precisely what allows athletes to be in harmony with the boat with no disproportionate waste of energy (as seen, instead, at **paragraphs 0.3** and **7.1**).
This phenomenon is tricky to describe without using equivalent mathematical models such as: moment of inertia, conservation of angular momentum, eccentric rotation, equivalent mass, etc.; I will therefore use similar physical phenomena without going into mathematical formalisms.
Accelerating part of the body while managing the repositioning of the centre of rotation is a phenomenon that recurs in several sports:

1. In the tennis or badminton smash, the movement carried out by the unoccupied arm pre-loads and, subsequently, helps speed up the arm holding the racket;
2. Almost the same thing happens in shot put and discus;
3. In athletics sprint running, the movement of the arms inertially balances the various stages of leg movement, including the body, which does not move height-wise by even one centimetre;
4. In the ice skating spin, spreading out the arms causes a reduction in angular speed up to 10%

of the maximum value;

5. In any circular movement the repositioning of the centre of rotation causes linear acceleration: this is visible in vibration motors, and it is also the principle that allows for a high jump using Fosbury's technique.

Radius2 is also useful as it can be a solution to an important problem: that of bringing yaw speed to zero. In rowing, the issue of body rotation affects boat pitch. It is a problem that trainers should easily be able to spot, and Base Technique is often used to attempt to solve such problems although, most of the time, concentrating on technique alone is not enough to fix it. In kayak yaw is often overlooked: trainers rarely place themselves behind the boat, athletes can only control the boat nose, and therefore this issue is often left to the athlete's own sensibility.

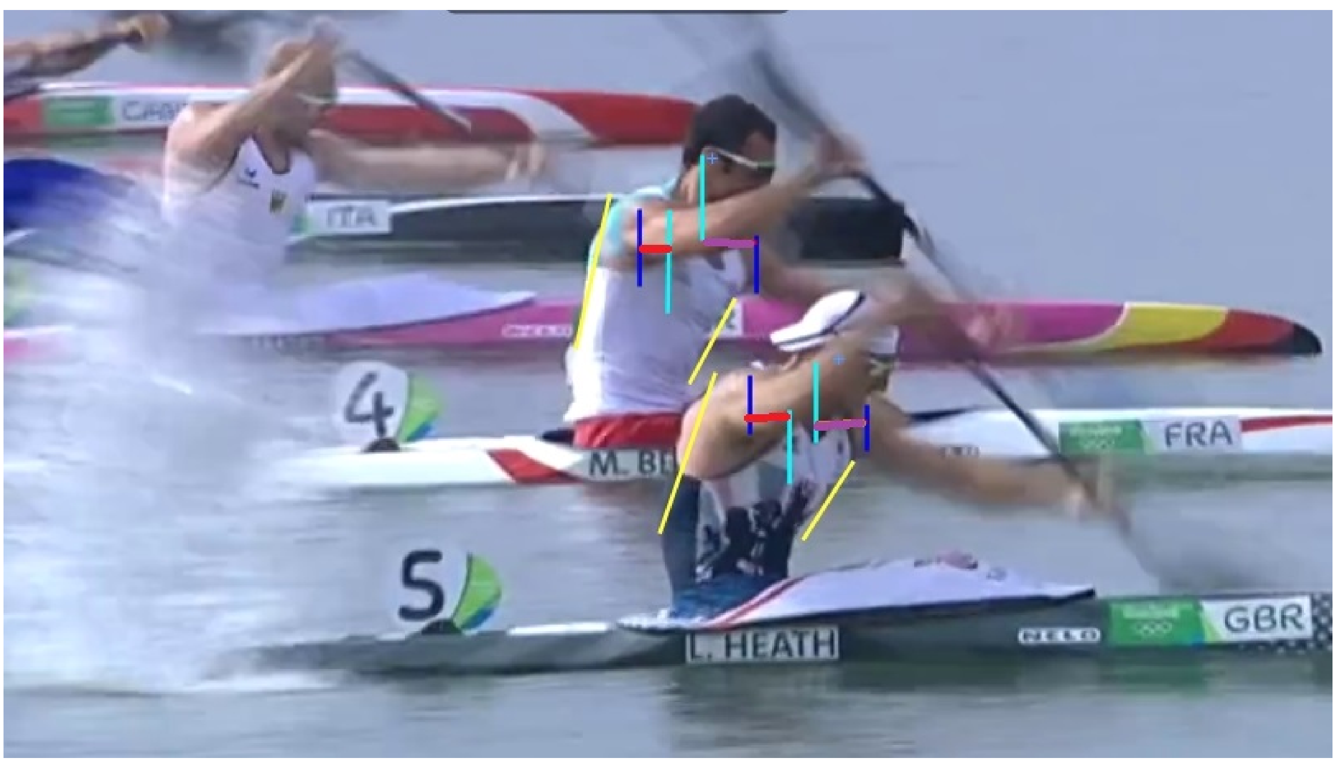
Before the end of traction, the body and boat's angular rotation impulses are opposed and can 'collide'. This may result in dispersion of energy, as well as generating random outcomes depending on yaw speed (note that, in the aerial stage, yaw speed slows the boat down more than any other dispersive phenomenon). Often, this is coupled with the body moving backwards, creating further dispersion of energy within the athlete-boat system, and for this reason we also call this 'intra-push'. Therefore in kayak, as well as rowing, a technical sequence must be carried out so as to avoid this type of collision.

When skaters or dancers wish to interrupt the fast rotational movement carried out in a spin, they will spread their arms out; for the same reason divers extend their bodies before entering the water. In rowing, the lengthening of the body itself provides the necessary inertial variation for the athlete to weigh less than the boat, as if they were unable to descend, like a spinning top. This phenomenon allows the athlete to delay the moment of 'descent' upon the boat by a few hundredths of a second: just long enough to end traction and pull the oar out of the water.

In kayak, inertial variation has to be thought of the same way as in rowing (although the plane of rotation is horizontal rather than lateral). The pressure exerted by the pushing foot, right until the end of traction, combined with the continuous increase of Radius2 allow the equivalent inertia between feet and hands to be so high as to reduce rotational speed with minimal dispersion of energy. In the space of a few hundredths of a second rotation is then brought to a complete halt by the final movement of the traction arm: this is made possible since, at that stage, the value of Radius2 is almost double that of inertia and, for the purposes of contrast with the blade, the body's equivalent mass is roughly ¼. In terms of physical similitude the same happens in rowing, with the difference that in rowing it is an easier phenomenon to spot since it lasts significantly longer and it can be observed laterally with respects to the athletes.

To summarise, in kayak the small forward movement of the torso in the aerial stage is prepared (accelerated) during the final stage of the previous stroke, by taking advantage of a slight lateral repositioning of the centre of rotation. This is a phenomenon associated more with good efficacy rather than maximum efficiency, since it recovers only part of the previous stroke's rotational energy. A better solution from a technical point of view would make better use of the body's and the paddle's elastic energy. Either way, studies will show that among the things that athletes who win K1 races have in common, there is this small forward movement of the torso in the final stage of water traction.

[Fig. 5.5a]



[Fig. 5.5b]

The only acceptable solution when dealing with yaw is the stroke's diagonal trajectory combined with a gradual increase of Radius2 and, additionally, the grip of the pushing foot right until the end of traction to augment the body's inertia. A different solution would not be successful.

Fig. 5.5a shows the Rio 2016 K1 M 200m finals. The vertical cyan segments show the position of the shoulders when athletes are halfway through traction. **Fig. 5.5b** shows both Heath and Beaumont from the left side, positioned for entry in water: both have brought their left shoulder forward (magenta segments) by a greater distance compared to the amount they have moved their right shoulder back (red segments). Despite noticeably leaning forward, Heath manages to keep the push very high, thus obtaining a Radius1 higher than that of his adversary. The value of Radius1 is the only difference between the two athletes as, for half the race, they proceed at the same stroke rate, %tWater and TotA (sector), as if it were a K2. Heath finishes in 1st place because his advance per stroke is greater by 0.02m (or, roughly, n100 = 42.0 against n100 = 42.4).

This is a thought-provoking race: it takes us back to very old methods, and makes us think of those trainers that used to athletes to gain one centimetre per stroke. But the problem is precisely that the old method is only successful in certain particular cases. In this race, thanks to the athletes' skills, all other elements remained unchanged. There are infinite combinations of parameters that produce good advancement but an overall deterioration. This latter point must be clear to all trainers: 'one size does not fit all'; we cannot use the same method on all athletes, even if the method worked for an athlete who, say, won the Olympics finals

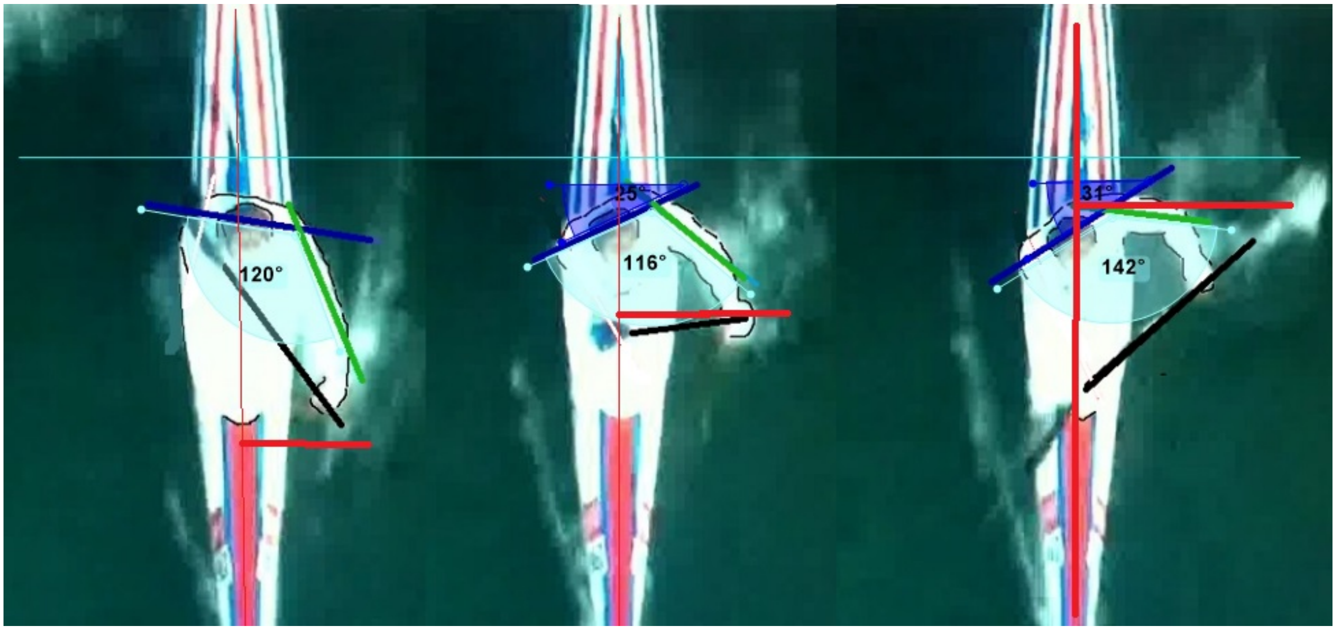
Despite not having a particularly vertical technique, kayaker Osipenko manages to annul the boat's yaw motion. This advantage is due to the fact that she uses a very high stroke rate and has excellent balance in the final stage of traction. It is important to point out once again that certain characteristics pertaining to very strong athletes are really just part of compensation methods which we know little to nothing about, and that are probably only suited to the one athlete. In this specific case, it is a reduction of propulsive efficiency balanced out with an increase in the efficiency of the boat.

Trainers and athletes must only attempt to duplicate successful behaviours, and understand the origin of mistakes in order to fix that aspect during technical training. It is only during technical training that we can ask an athlete to eliminate all forms of compensation: this is because in that way the boat proceeds at a significantly lower speed, something that would not be psychologically easy to accept in normal training, especially if there are other athletes present. When we ask the athletes to carry out the movements correctly, some Step1 parameters can come in handy as feedback. We could measure the n100 and tell the athlete that, for instance, he has moved from n100 = 48 to n100 = 42 (and point out to him or her that it is the same advancement as Heath had in the Rio 2016 K1 M 200m finals). This is not only psychologically acceptable, but also extremely motivational.

5.6 – Changing the Transmission Ratio; The Angle Between the Shoulders and the Traction Arm

In this section we will once again talk about athlete Rodriguez, whom we have seen in **fig. 4.1**. **Para. 5.1** mentions what has been observed when changing advance per stroke from n100 = 38 to n100 = 40, i.e., a reduction in the angular sector from 110° to 100°. If the subject matter happened to be a bicycle, we would be talking about a change in the transmission ratio. In the present case the situation is different, but there are several analogies. The variation in the angular sector is not a rule; it is simply what I have observed. I have associated this variation to race success because the athlete in question won the race, because the race graph is similar to that of other winning athletes, and because no other visible technical changes were carried out.
It is, generally, every trainer's primary objective to succeed in changing one parameter by perfecting the desired element without changing everything else. It is also the real purpose of this paper: to give the necessary information so that trainers can build on technique by changing one element at a time.
But how do we go about changing the angular sector in the right way? (Please note that, contrarily to a technique class, this paragraph provides parametric information on how to obtain the desired variation or change without having to alter technique).

Fig. 5.6 shows athlete Edward McKeever at the London 2012 Summer Olympics 200m Finals A, which he won. The figures are not as accurate as they could be, but they cannot be measured again as the video is no longer available on YouTube. However, they still give us a good idea: the angle formed by the green line (arm) and the blue line (torso) in the beginning decreases from 120° to 116°. It remains stable at 116° until the body ceases its rotational movement and the motion switches to the upper limbs. This angle is geometrically linked to Radius2, which is shown with horizontal red lines. The angle is therefore the simplest element that can be used to change advancement.



[Fig. 5.6]

If during the stroke action the angle was equal to 90°, it would result in a lower angular sector and reduced torque with equal force on the blade. We can therefore assume that Rodriguez simply altered the size of this angle, thereby also reducing Radius2. This is one of the many methods that we can use to lighten the stroke, but it is the only way to do this without also reducing rotational speed and Radius1. Please note that Radius1 is proportional to the inertia of the mass of water upon the blade.

Finally, we can see that athletes who reduce Radius1 – even if they do so only at the initial stage or end stage of the stroke – will have to work extra in a vertical sense in order to increase the hydrodynamic power necessary to avoid blade slip. As shown in **fig. 6.1b** the Austrian athlete fails to compensate as described and ends up losing 12cm with each stroke, arriving 5" behind the winner Rodriguez.

In many cases it would be very useful for athletes to be capable of achieving good efficiency with a wide range of different stroke rates. For example, an athlete who trains with a value n100 = 30, but races with a value n100 = 40, risks disregarding technique and could then have difficulty adjusting to the lower advancement figure. The purpose of inserting and removing a hydrodynamic brake is indeed that of maintaining technique while altering only stroke rate.

Of course there is still a lot to be learned regarding the possibility of simultaneously increasing both efficiency and efficacy. Any method that involves varying either radius (Radius1 or Radius2) cannot be ideal, since there are rowing crews that are able to find successful solutions when there is a variation in the advancement (especially in the last 500m), and in rowing the boat settings make it so the radii are virtually fixed.

Chapter 6: Hydrodynamic Phenomena

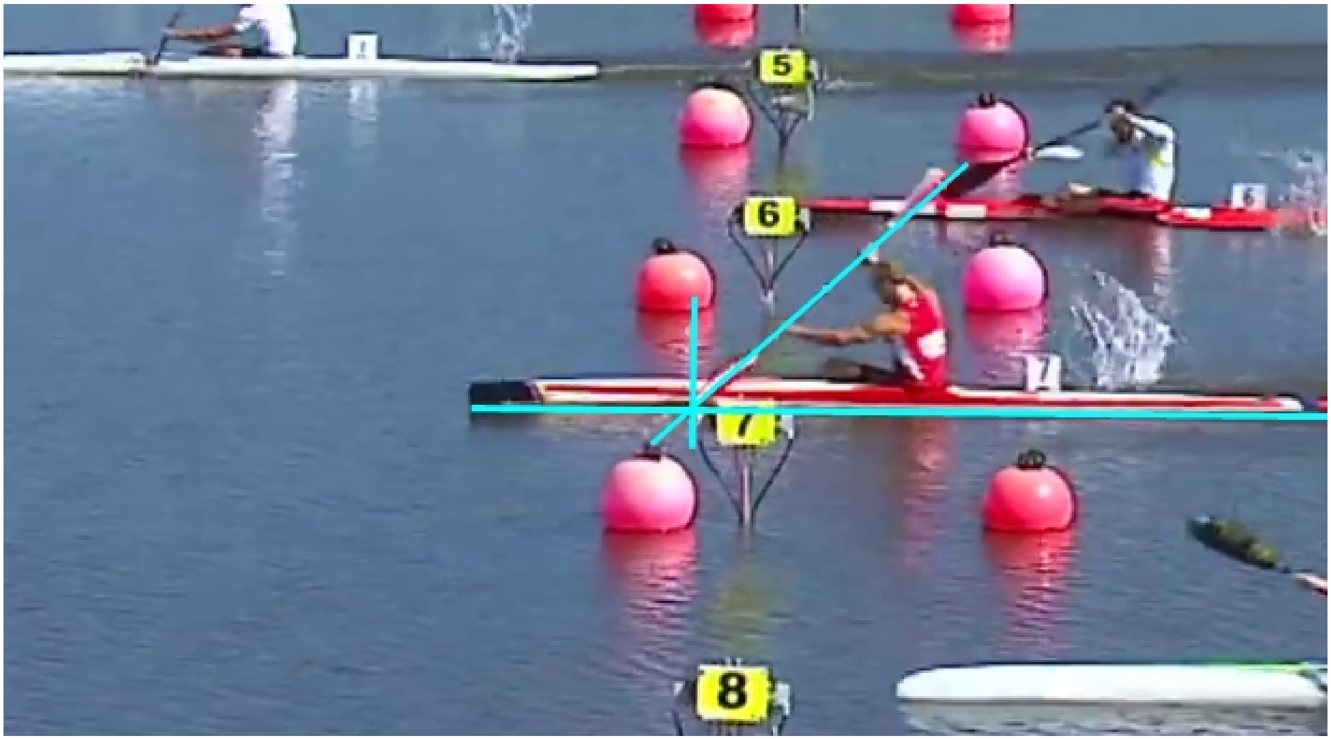
6.1 – A closer look at inertial motions and hydrodynamic effects; Using augmented reality to test hypotheses on dynamic behaviour; Elements of Micro-Technique.

In the race previously discussed in **Chapter 4** (**fig. 4.1**) the athlete Kornfeind (AUT) convincingly demonstrates how uncompensated errors can lead to a great loss of efficiency.
Figures 6.1a and **b** show Kornfeind passing the 500m line in lane 7. The fixed camera allows us to measure blade slip in water: the value of 0.12m indicates a great amount of energy dispersion. Consider that the ideal blade slip in water amount is 0. This value is calculated systematically based on the majority of World Cup Finals A athletes.

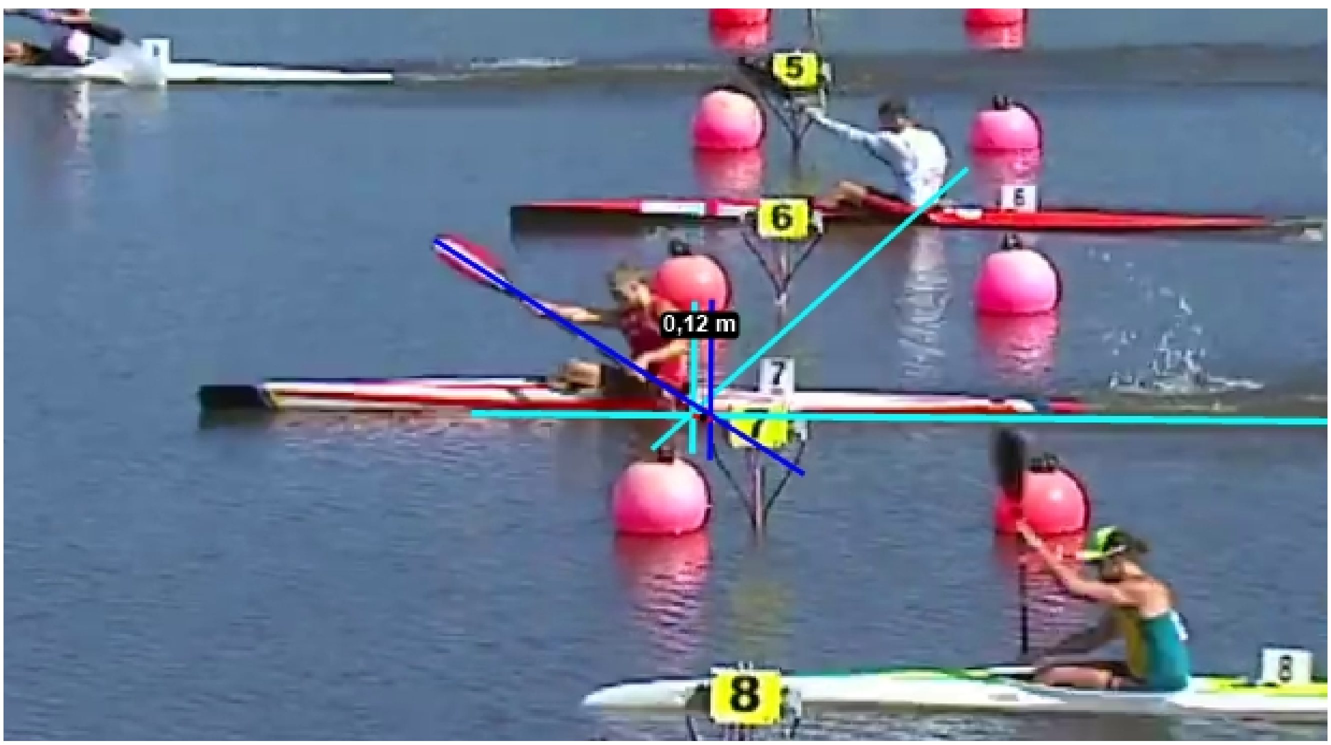
Although it would go beyond the scope of this paragraph to measure the remaining parameters, I wish to point out that the slip results in the athlete moving backwards (intra-push). This is because, on the traction side, in the final segment, the water does not provide enough support. This leads us to an important point: the equivalent mass connected to the paddle by the athlete in relation to the water is not proportional to the athlete's weight; in fact, it escalates rapidly depending on the athlete's weight combined with his or her 'geometric shape' (in engineering terms, it is the body's moment of inertia added to the boat's moment of inertia). Athletes who are relatively big in size and broad-shouldered may find it advantageous to also carry out a rotation with the pelvis. However, if it is carried out impulsively and the transmission is too stiff, they will run the risk of destabilising the balance of inertias at play. As can be noted from the above images, the athlete Dostal proceeds with a very small leg range, thus probably preventing this phenomenon from happening. Therefore, compared to Kornfeind, Dostal uses a seemingly less efficient technique, because of the legs' limited motion, but it nevertheless allows him to avoid slip and yaw. Dostal is merely compensating in a more beneficial way. From the point of view of results, it is always best to compensate errors with ability, rather than applying technique in a pedantic way and ignoring Meta-Technique. Removing all forms of error compensation is crucial when undergoing technical training, so as to be able to pinpoint and fix them.

Before analysing **fig. 6.1c**, please take a look at the image pictured in **fig. 6.1d**, which shows the last few metres of the Rio 2016 K1 1000m Finals A. This image gives us two pieces of information:

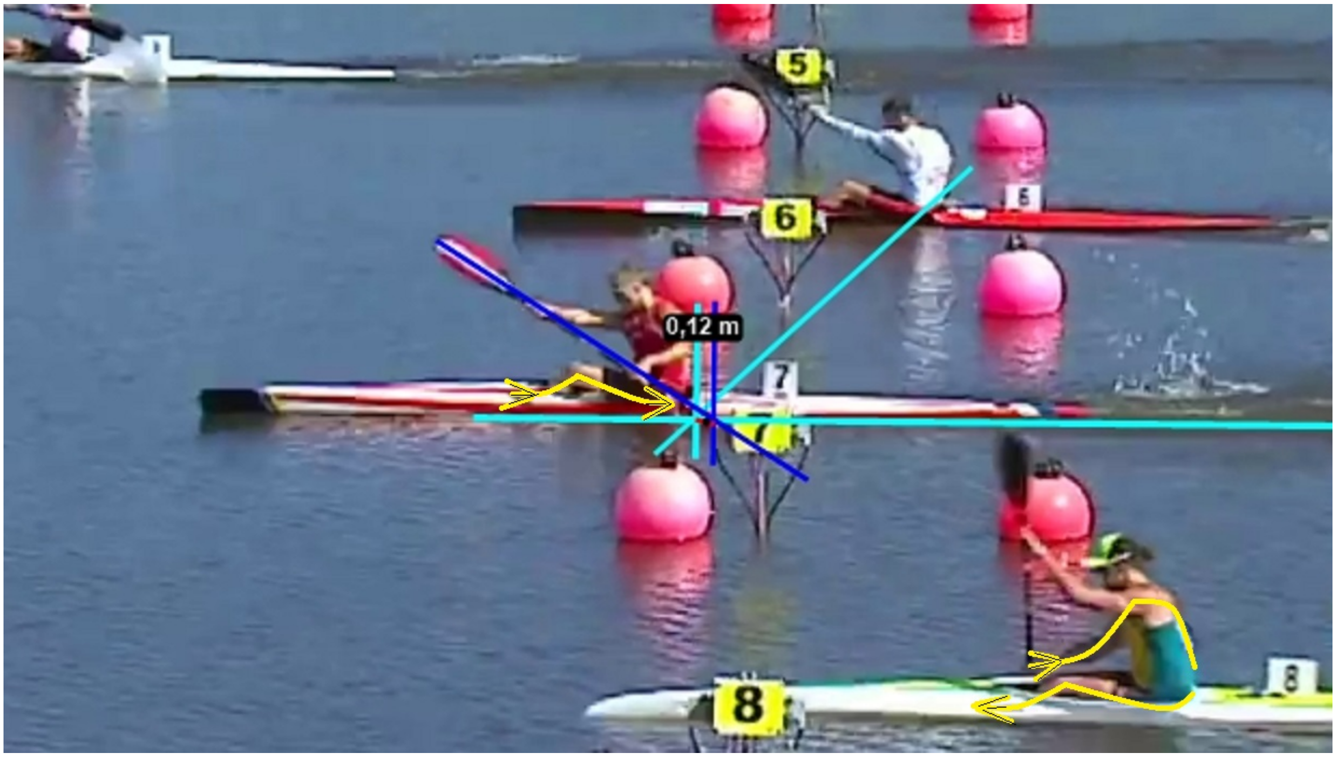
1. Walz's left shoulder moves forward (magenta segment) more than his right shoulder moves back (red segment). This is the same phenomenon pictured in **fig. 5.5b** (Heath). We can finally show what happens when athletes move back (Dostal); and
2. We now have further elements on the key element that we are studying, i.e., the hydrodynamic actions that appear invisible on film. As you can see, some black lines have been added to highlight in an exaggerated way a hypothetical push or counter-push before entry. Further on, we will see other elements that support this hypothesis.



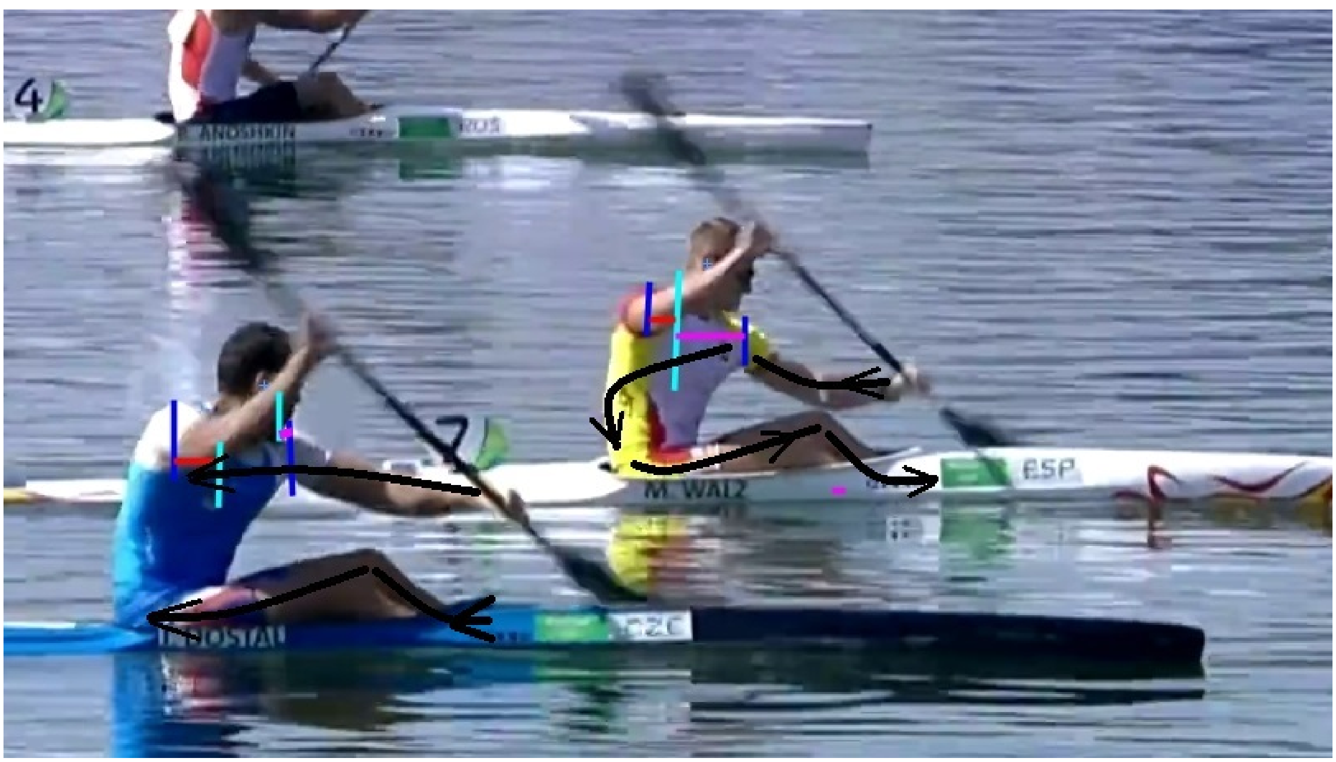
[Fig. 6.1a]



[Fig. 6.1b]



[Fig. 6.1c]



[Fig. 6.1d]

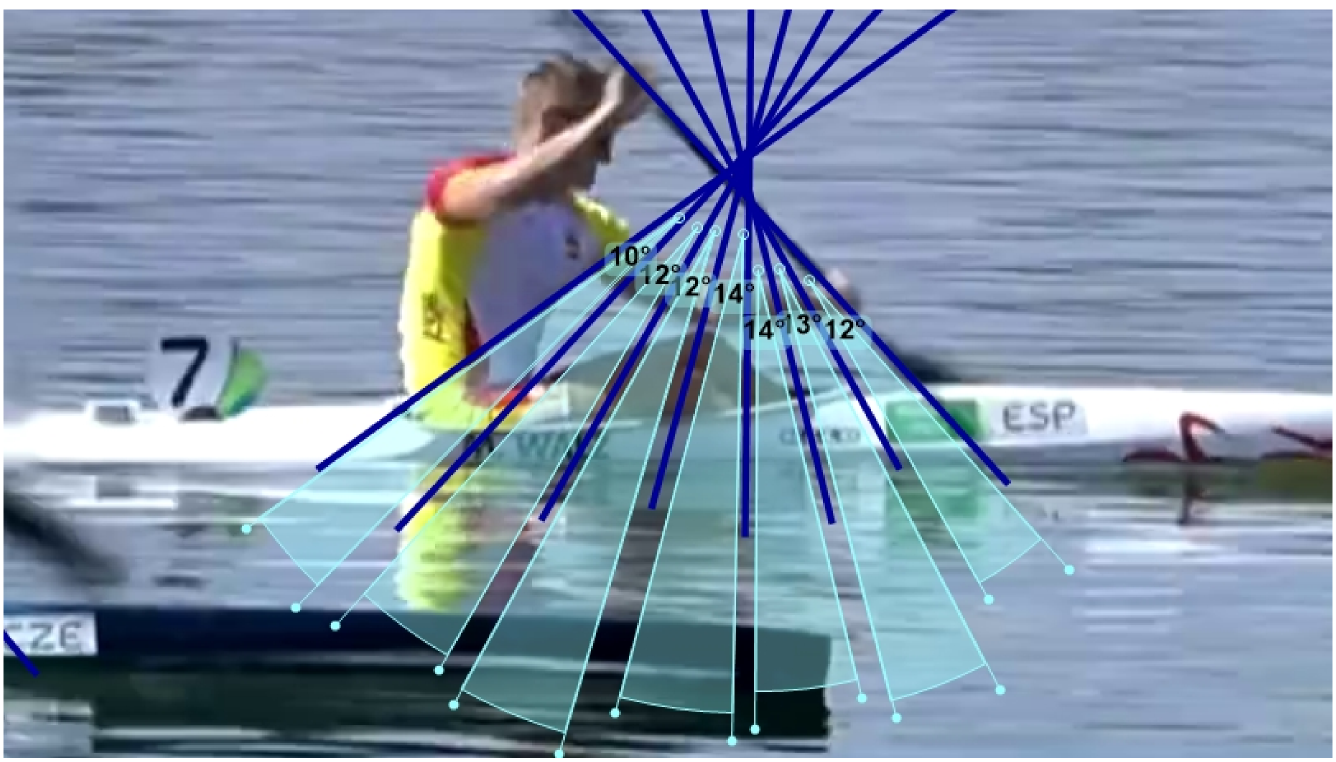
It can therefore be assumed that, before entry, Walz had already pre-loaded with the 'correct' (*) pressure on the footrest, thrusting his body forward to carry out acceleration with his body and boat with no unnecessary collisions. (*) The athlete can use the footrest to counteract the boat's brake force in order to pre-activate the leg muscles, rather than using the seat.

It can be useful to remember that the portion of force responsible for accelerating the entire mass in a forward-motion is mainly focused on the athletes' bodies, at the boats weigh only 12kg. The towing portion of the applied force (i.e., the force that, if applied continuously, would allow the boat to move at the same speed) seems to actually shift from the left hand to the left foot and footrest. In this case the torque applied with the right foot would balance out the other torque applied with the right arm, and this torque would be the means of producing that additional force that the athlete has to deliver to the entire mass (and, therefore, to a small extent, also to the boat itself), in order to balance out the fact that no force is applied in water in the aerial stage. The calculations for this will be further analysed at **para. 8.2**.

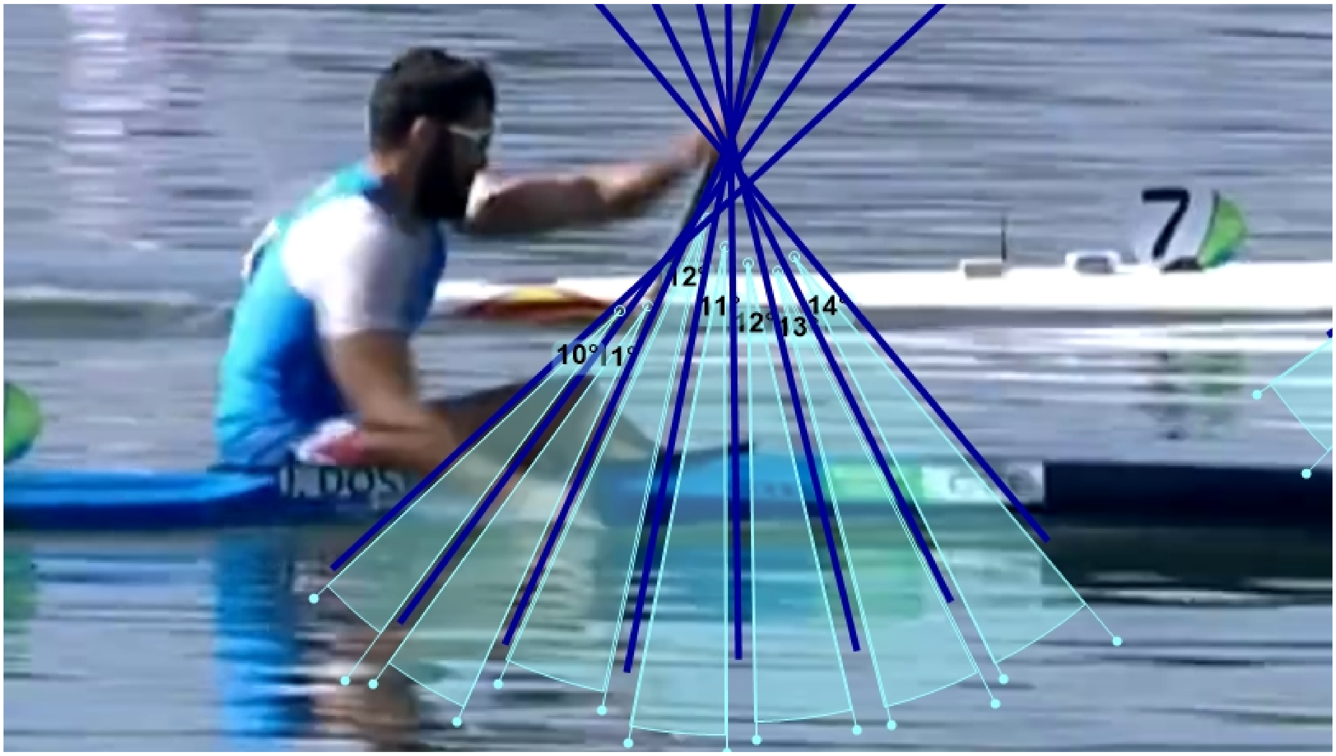
In **fig. 6.1d**, we can see that Dostal is positioned backwards compared to the position he holds halfway through the stroke: his body therefore moves forward during the first half of traction. This makes it very difficult to correctly pre-load the muscles of the left leg, and, furthermore, it makes it so that he has to apply increased force during the stage of entry in water in order to bring his body forward. These actions, combined with the fact that the athlete's motion is not in harmony with that of the boat (pitch and surge) can hinder the correct interaction between blade and water (**para. 0.5**). This hypothesis is reinforced from what we can see in **figures 6.1e**, **f** and **g** (similar to **fig. 5.2**), which show respectively Walz's and Dostal's sequence of paddle angular speed. (Rio 2016 Olympic Final K1 M 1000m). In **figures 6.1e**, **f** and **g** we can see that Dostal enters with an angular speed of 14° per frame; higher than Walz (12° per frame). This difference is even more significant given that Walz's stroke rate is significantly higher than Dostal's. **Fig. 6.1g** shows Dostal performing the same stroke as in **fig. 6.1e**, but pictured halfway though the stroke. We get the impression that Dostal moves forward during the first half of the stroke, and this represents another way of performing extra-pull. Please note that this phenomenon cannot lead to perfect efficiency, but it is nonetheless the exact opposite of a mistake that would result in the simultaneous loss of both efficiency and efficacy, i.e., intra-push.

Moving back to **fig. 6.1c**, athlete Bain (AUS) in lane 8 can be used as an illustration of the augmented reality system. The yellow arrows show the presumed applied forces (**fig. 6.1b** shows the same image without the yellow arrows). One of the yellow arrows indicates the counter-push on the right foot of the athlete in lane 7: this action can be said to be correct, but the athlete is definitely doing something else incorrectly. The athlete in lane 8, on the other hand, despite being halfway through the stroke, seems very relaxed, to the point where he carries out the pulling motion using only his right hand to balance out the force that pushes the boat with his right leg, as if all the other forces applied were less significant.

[Fig. 6.1e]



[Fig. 6.1f]



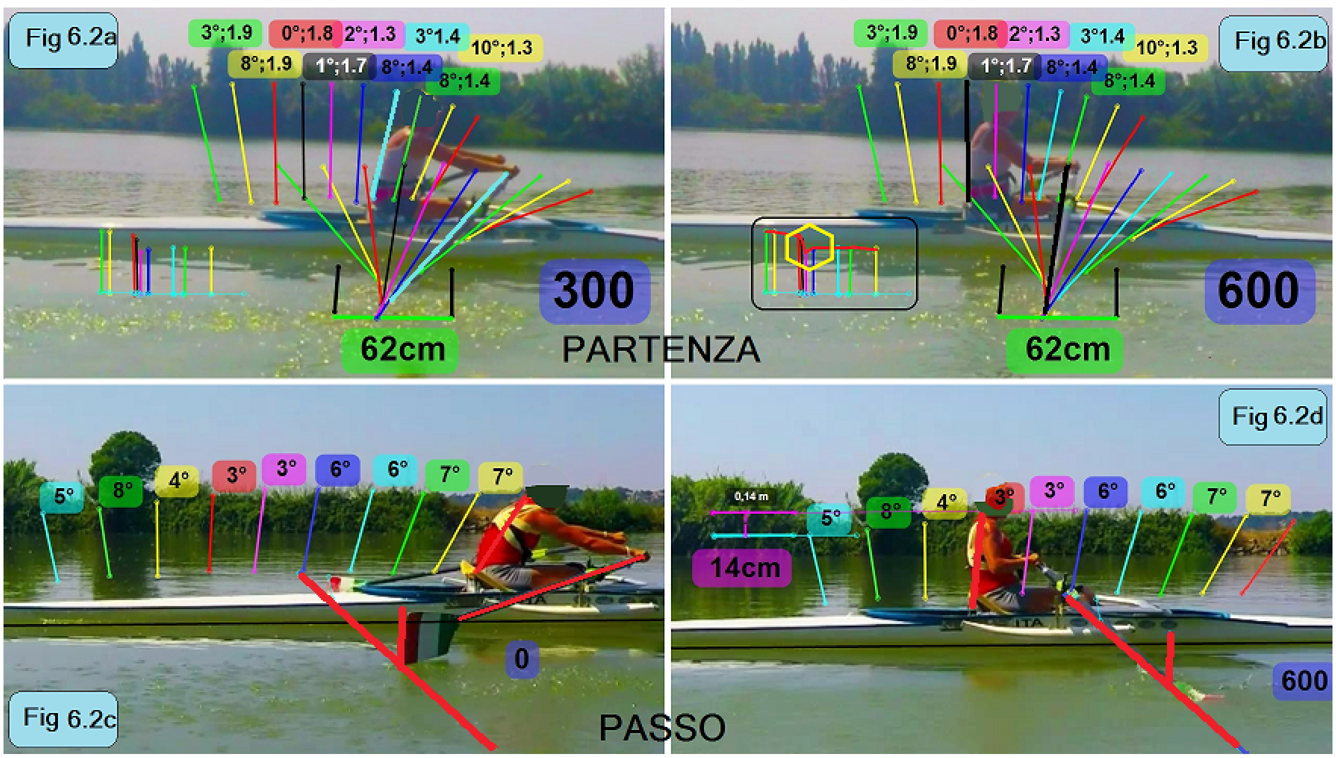
[Fig. 6.1g]

Obviously the Australian athlete (who finished 2nd, 1.7” behind first place and 3.4” ahead of the Austrian athlete) also had to apply additional force to balance out the fact that, during the aerial stage, no force can be applied. He manages to do so in an almost imperceptible way, with maximum efficiency. This athlete shows no distinctive characteristics: he is simply at one with the boat and never performs any unnecessary motions. Please note that, although we often see winning athletes performing extra-pull motions, these are nonetheless dispersive actions that should be avoided. The balance of inertias is essential if we want to optimise the interaction between the athlete and the water, and it is carried out using a mix of intuitive feeling and flexibility.

Flexibility and the motions of athlete and boat (pitch, surge, yaw) represent the ‘energy bank’ (*) that athletes must manage in order to avoid waste. (*) The term ‘energy bank’ refers to the energy that is transformed with each stroke phase. A very rough estimate could put it somewhere between 20 and 40 Joules, based on the maximum rotational speed. Athletes capable of recovering even only 10 Joules of this energy that would otherwise be dispersed will obtain additional power equal to about 5%, and gain 4” over 1000m. The same could be said regarding the energy of the paddle’s elastic deflection: if the paddle yielded 5cm with every stroke, since the advancement made with a single stroke is very close to 1m we will be left with a percentage of energy equal to 5% that must be recovered before completing the stroke: we would therefore have a further 5% and 4” on 1000m. Several other elements of Micro-Technique lead to energy-related results that should make us stop and think: it is wiser to address these phenomena rather than wasting time looking for a different boat and gaining, perhaps, 0.1”.

6.2 – A video analysis on the dynamic effects in rowing

Adaptive rowing is a key element when analysing boat behaviour in relation to the inherent problems faced by the analysed categories of athletes. We will now see a case where a TA (Trunk & Arms) category athlete blocks her legs. This limitation in itself causes significant variations in the handling of hydrodynamics. Athletes in the TA category faced with problems concerning the transmission of force in the muscles of the torso will exhibit a similar behaviour to that of AS (Arms & Shoulders) athletes, who tend to have problems of discontinuity in the active stroke stage. We will see how this discontinuity impairs the entire chain of force transmission, and also affects the cyclical nature of movements, as in the steady distribution of kinetic and elastic energy between athlete and boat.



[Fig. 6.2]

The advantage of conducting this type of analysis is the soul of this whole paper.

- From a first analysis – whether conducted live or from a video – we can, albeit with some difficulty, discern this phenomenon;
- The next step is to use the methods of assessment on athletes who are ‘close to perfection’: we already know what needs to be measured and how to help them improve; and
- After having conducted several video analyses we will no longer require the aid of video footage since, by now, we as trainers will have enough experience to be able to spot the phenomena at a glance.

This being said, we cannot make the mistake of thinking that everything will be visible to the naked eye. If there are any difficulties it is always a good idea to study the video footage with all the elements of Step 1 and Step 2 in order to check whether the current problem is among those that we are unable to effectively discern.
The point is, no trainer is perfect. Trainers who do not possess a method to evaluate and map out in writing the problems encountered will not even be able to turn to their colleagues for help. This happens because of the difficulty of put an invisible phenomenon into words.

Video footage of a TAW1x (adaptive rowing: Trunk & Arms Women single scull) highlights an error that has an established cause and effect.
Fig. 6.2 is taken from one of my previous papers (*05). It shows the second stroke of a standing start (TAW1x athlete), 0.300" after water entry. The coloured lines represent the position of the athlete's back and oars at 0.1" intervals. The athlete's back and the oars are positioned on the cyan lines.
The angular variation of the back and the boat speed are measured at 0.1" intervals. The first measurements at 0.1", shown in the yellow box, are 10° and 1.3m/s. The 10° figure represents angular speed: it is the degree of increase achieved in 1/10th of a second, adding up to a 100° increase per second.

At the second interval (green-coloured) we can already begin to notice a reduction of the back's angular speed (8° in 0.1" = 80° per second), followed by an even further reduction (with a mere 3° increase in 0.1" = 30° per second, cyan-coloured). In box 'B', at the time 0.600" (black-coloured) the arms have already replaced the work previously carried out by the back. The back stops moving, and as a consequence the boat gains speed (from the point of view of physics this can be seen as a veritable collision – as if the athlete's back had collided against the backrest typically present in AS boats, which is not, however, present in this case). This is truly disastrous: to clarify, the boat travelled 0.55m until the blue line (after 0.4"), whereas the body travelled 0.68m (using the diaphragm as reference as the possible centre of mass). Therefore, if boat speed was around 1.4m/s, the body's speed was higher, about 1.7m/s. *The aim of technique is to equalise these two speeds by making boat speed equal to body speed, and not vice-versa.* Instead, in the present case we can see how, at the following frame (fuchsia-coloured, time = 0.5") the boat speed actually decreased to 1.3m/s. Hence, with the correct technique and back stiffness the final speed of the first stroke would be higher by 0.4m/s.

Besides, all this stress on the oars, both in the water and on the oarlock, causes the water around the blade to become unstable, thus resulting in a significant oar slip equal to 0.62m.
The same operation is repeated during constant-speed training, shown in **fig. 6.2c**. This presents no problem in the first 0.4" (up to the blue-coloured segment), but then the arms proceed to slow down the back movement (still only halfway through the stroke), and the scene is set for a predicable event, namely, water blade slip.

Let us take a quick break from stroke analysis to point out something that is very important: in this situation, the height of the hands relative to the seat of the boat is a good approximation for Radius 2 (**para. 5.5**). Since balance, with respect to angular speed variations from the torso, depends quadratically on Radius 2, it would be sufficient to adjust the oars to a slightly lower height in order to lighten the load on athletes' backs, thus avoiding the problem altogether. Still, running away from problems is never the right solution. Athletes will still have a great amount of muscle imbalance and, in order to succeed in this discipline, they must give up a fleeting improvement and try to make better use of their backs following their trainers' directions.

In rowing, therefore, athletes cannot reduce Radius 2 without altering the boat settings – on the other hand, they can increase it by further submerging the oars. This latter action is interesting because, although it is considered an error, it is a characteristic pertaining to Drysdale, Rio 2016 Olympic champion. Before we can conclude whether an athlete is making a mistake, we must keep in mind that increasing Radius 2 decreases athletes' equivalent inertia on the oars. Athletes who are particularly heavy may find that this is the only way for them to adapt to water inertia, which, halfway through the stroke action, may be inferior and cause oar slip.

This phenomenon tells us a lot more than the adjustment of a single parameter: athletes who weigh less must proceed with very different settings compared to heavier athletes, even in cases where they have the same anthropometric measurements. *Meta-Technique (in this case, the balance of inertial forces) dominates over trainers' geometric intuition.*
On the contrary, kayakers can decide to change the value of Radius 2 between one stroke and the next. This is a great advantage in the short- and medium-term, but can also be a limiting factor in the long-term.

Fig. 6.2d shows the last moment of active propulsion (marked in red). After that, the oars begin to slide out of the water and the athlete's back speeds up again, causing serious problems in the aerial stage and during the next stroke.
The fact that the back speeds up again (**fig. 6.2d**, marked in green) is due to the lack of water 'grip' by the oars, but also because the athlete bends her back, thus reducing rotational stability (like in the spinning top example made above to illustrate a principle of physics). According to technique, 'stability' is reached by pushing down with the feet (and, if personal strength allows it, by correctly dealing with the partial suspension from the seat): *therefore, the lever that allows for this phenomenon can be equal to either half the length of the athlete's back, or to the athlete's full height from head to toes.* Overall efficiency depends greatly on this simple application of technique.

Let us look back to the kayaker in **fig. 5.2**. In this case also there was a variation in the paddle's angular speed. Having now seen what happens in case of an extreme error where the athlete's back freezes and then starts moving again (**fig. 6.2**), we cannot allow ourselves to disregard a variation from 10° to 8° in the almost central stage of a motion. The biggest suspect is the group of muscles in the shoulders. Athletes are not in the habit of fixing these muscles. At lower speeds, this does not present a real problem in terms on efficiency, but at higher speed it becomes one of the biggest obstacles to surmount.

6.3 – A dynamic analysis of rowing carried out with inertial sensors

Numerical data is collected by means of a boat's inertial sensors.

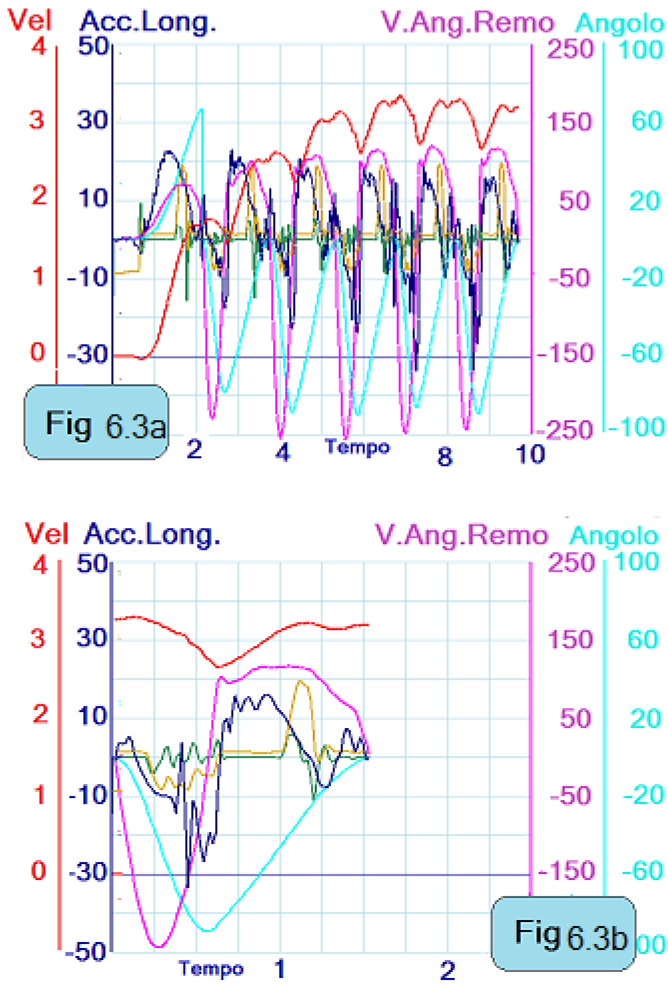
AS1xW (adaptive rowing) (*05).

Fig. 6.3a shows the data collected at the start of a race, in the first five strokes of a single AS (Arms & Shoulders):

1. Red – speed;
2. Blue – longitudinal acceleration shown in hundredths of a G (where G = gravitational acceleration = 9.81m/s^2);
3. Magenta – oar angular speed;
4. Cyan – oar angle (angular sector).

Fig. 6.3b shows the same type of graph, but only the fifth stroke.

The data is shown as a verification of a direct measurement of the phenomenon observed at **para. 6.2**. What we do not see here is the variation of body speed compared to the boat. We know that also in this case it occurs after the first half of the stroke, but for different reasons, although the effects are the same. The boat's acceleration becomes negative for around 1/10th of a second, approximately 30° before the end of the stroke (the total sector is around 90°). It must be pointed out that technique on this particular boat is different from that which we would normally expect, but it is a circumstance similar to that of a failure in the transmission chain of an averagely skilled athlete. What happens is that there is a statistically certain dispersion of energy caused by an impulse (a veritable collision) between body and boat. Moreover, as further confirmation that the boat's phenomena directly affect propulsion (the cornerstone, **para. 0.3**), the stability of the oars in water is compromised. Any acceleration of the boat will affect the oarlocks, which in turn significantly affect the oars. In certain cases there is a total discharge of the elastic energy accumulated in the oars and an anticipated release of the oars in water.


Vel
Acc.Long.
V.Ang.Remo
Angolo
4 3 2 1 0
50 30 10 -10 -30
250 150 50 -50 -150 -250
100 60 20 -20 -60 -100
Tempo
2 4 8 10
Fig 6.3a
Vel
Acc.Long.
V.Ang.Remo
Angolo
4 3 2 1 0
50 30 10 -10 -30 -50
250 150 50 -50 -150
100 60 20 -20 -60
Tempo
1 2
Fig 6.3b

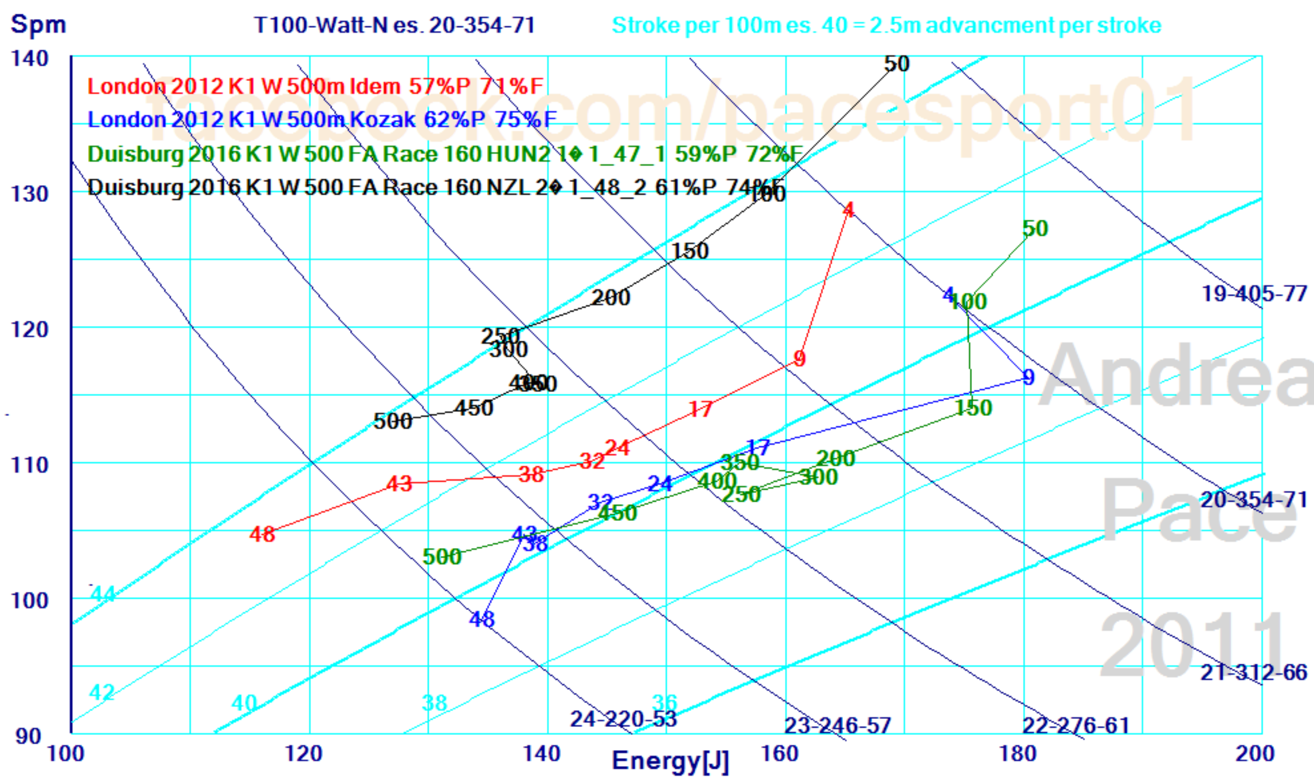
[Fig. 6.3]

Chapter 7: The H-Graph and Step 2

7.1 - K1 W 500m; H-Graph

Fig. 7.1.1 shows the H-Graph of the Hungarian athlete Danuta Kozak winning two races (marked blue and green). Additionally, it shows a comparison between the data relating to Josefa Idem (marked in red) in the London 2012 Olympic finals K1 500, and the New Zealander Lisa Carrington (marked in black, Duisburg 2016).

The graph of a 500m race is very different from that of a 1000m one. In a 500m race the principal mode of proceeding is ‘constant advance per stroke’. There are several sections where speed and rate will decrease in a uniform manner; then there are critical moments where we can see the way in which tactics have been implemented.



[Fig. 7.1.1]

One race at a time:

1. **Josefa Idem**, K1 500m W London 2012, marked in red. Between 80m and 380m the athlete largely proceeds with constant advance per stroke, with a value n100 = 41 (approximately). As mentioned above, and as will be further discussed at **para. 8.2**, attempting to interrupt speed reduction even for a very short period of time requires great effort. We can see that between 240m and 320m (red tags no. 24 and 32) the

athlete maintains the same frequency and speed. In this segment, she must apply more force since the boat is no longer slowing down, and this can be a problem since, as the race goes on, the available strength decreases. We have seen how in 1000m races the best athletes will attempt to somehow change advancement while they still have the energy to do so. In this case, advancement changes to n100 = 43, and instead of earning a bronze medal the athlete finishes in 5th place. In the stages of the race where she is losing speed, Idem should have transferred roughly 0.5kg less energy (the calculation is shown at **para. 8.2**). Looking at the graph in **fig. 7.1.1** we can see that at 80m (red tag no. 8) Idem is close to the average force hyperbole equal to 66N, whereas between 170m and 240m she is close to the average force hyperbole equal to 61N. The difference of force between the 80m mark and the 200m one is significant; it amounts to 66N – 61N = 5N, or a weight of 0.5kg. Maintaining speed between 240m and 320m requires the same amount of force that the athlete had used in a previous segment of the race. This means she made a tactical decision. We shall see further on that her opponents used a similar tactic but only *after* having overtaken their own direct opponent, as opposed to using this tactic to overtake her in the first place.

In this case the athlete had to choose between two available tactics:

- Continuing the action with an advance per stroke value n100 = 41, following the ‘physiological’ decline and trusting that better efficiency would allow her to gain those few tenths of a second necessary to earn a medal;
- Changing ‘relationship’, similarly to what is shown at **para. 5.6**, so as to have the correct amount of energy per stroke in order to increase frequency and finish the race with constant advance per stroke and n100 = 43, trusting that in the final part of the race she would have higher frequency and increased speed.

2. **Lisa Carrington**, K1 500m W, Duisburg World Cup 2016, 2nd place. She proceeds with constant advance per stroke up to the 250m line, with a value n100 = 44. After 250m she begins the action of overtaking Osipenko, currently in first place. Up to 400m she maintains constant speed while reducing stroke rate; she then starts to lose speed but nevertheless succeeds in overtaking Osipenko and coming in 2nd behind Kozak. In this case the race segment between 250m and 400m (i.e., the segment where speed is kept constant and stroke rate is reduced) suggests there are two main elements worthy of consideration:
   - The first one is purely tactical: in order to pass Osipenko as quickly as possible, Carrington maintains a high stroke rate until the 250m mark (greater than 120spm). Once positive she is going to succeed in overtaking her opponent, she reduces stroke rate in order to avoid draining her own energy and finding herself unable to finish the race with low efficiency;
   - The second element concerns hydrodynamic efficiency: the athlete decreases frequency for the purpose of applying reduced power. In the next 150m she manages to maintain speed using less power, denoting increased efficiency. At this point the athlete chooses a value n100 = 44. We cannot know whether this was the only way

she had to preserve efficiency, or whether it is an emotional reaction due to the fact she has just passed her opponent. Thanks to an inspired tactical choice we have randomly discovered that in order to obtain maximum efficiency advance per stroke has to be a lot higher, with a value T100 equal to or greater than 43.

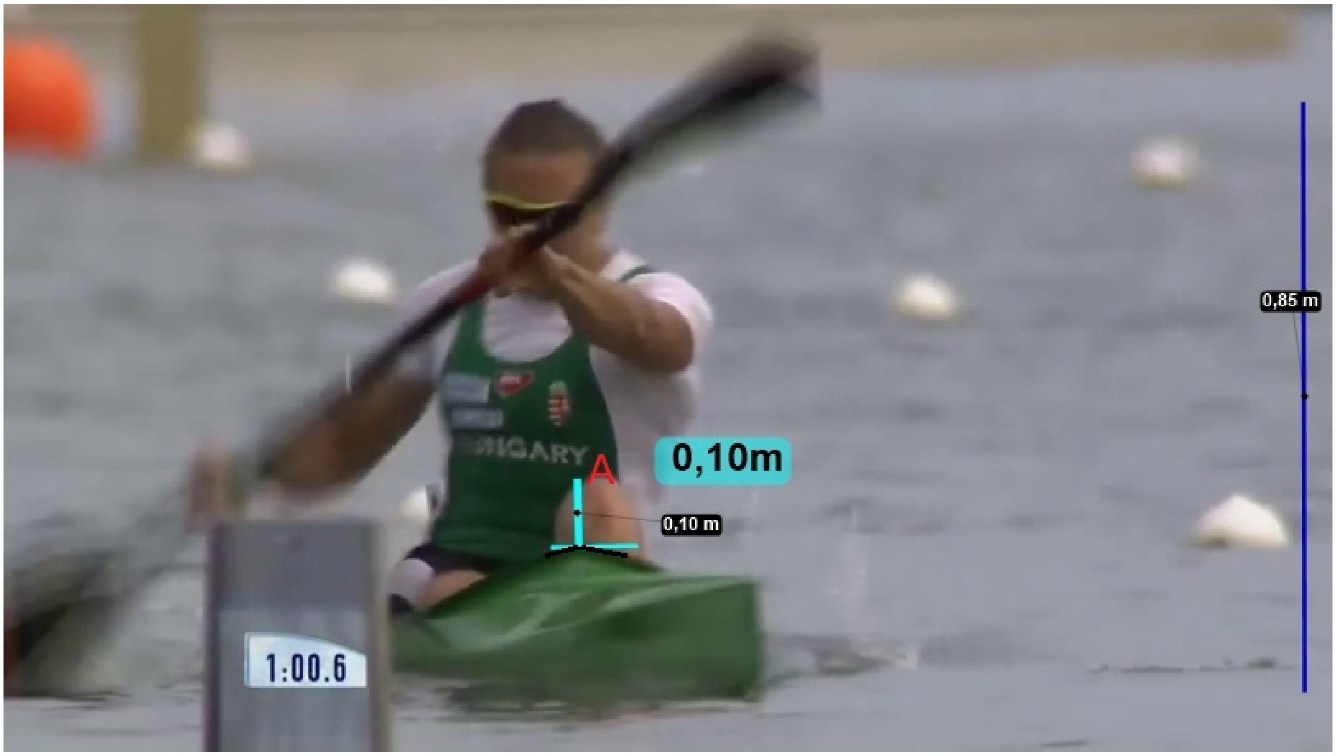
3. **Danuta Kozak**, K1 500m W, London Olympics 2012 (marked in blue), and K1 500m W Duisburg World Cup 2016 (marked in green). The athlete won both races with a constant advance per stroke n100 = 40. In the London race, something happens between 380m and 430m, something that occurs after overtaking, having already secured first place at the 350m mark. The athlete seems to prefer delaying the physiological speed decline since she still has enough strength to withstand the extra force of 0.5kgf (Kilogram-Force) that must be applied when proceeding at constant speed. In the Duisburg race she begins the action of overtaking Osipenko between 250m and 300m. She manages to increase speed while maintaining constant advance per stroke; afterwards she increases speed significantly with a small increase in stroke rate. Please keep in mind that, during the race, athletes can easily verify advance per stroke since it is very close to the value of 4 strokes each buoy passed (the buoys being 10m apart).

7.1b – K1 W 500m; Step 2

The most evident characteristic when watching Danuta Kozak is the boat's pitch motion, driven by an equally manifest forward movement of her torso. We have no way of knowing whether this is the best course of action for the athlete, but we do know without a doubt that it is effective. From the H-Graph we can also see that it is an action that allows her to maintain a constant level of efficiency throughout the race.
As mentioned in the cases at **fig. 5.5a** and **fig. 5.5b**, it is an extra-pull performed with more evident motions. Since any motion that requires the boat to have a large pitch angle is quite energy consuming, such a motion much have some great advantages. Let's see what these are.

Fig. 7.1.2 and **fig. 7.1.3** show Kozak in the Szeged 2014 K1 500m race. Below is an example of what could be considered a good dynamic action in kayak. The introduction mentions the kayaker's dual task: the first is to use constant force to push the boat.

Fig. 7.1.2 show Kozak at the moment when the blade is exiting the water on the her right side; her left knee is 0.10m above the tip of the cockpit (red-coloured letter 'A'), and is in line with her left foot, which is 'counter-pushing' (i.e., traction), and appears near boat's centre-line, but not quite on it. Although we do not see it, in the next frame the pitch is inverted, since the left foot has already started to push. Keep in mind that the muscles of the leg pushing on the footrest can be activated in advance of water entry, thus contrasting the nearly 7kgf which the boat constantly needs in the form of a pushing force. Athletes who do not take this opportunity perform the pushing motion by using the seat of the boat.



[Fig. 7.1.2]

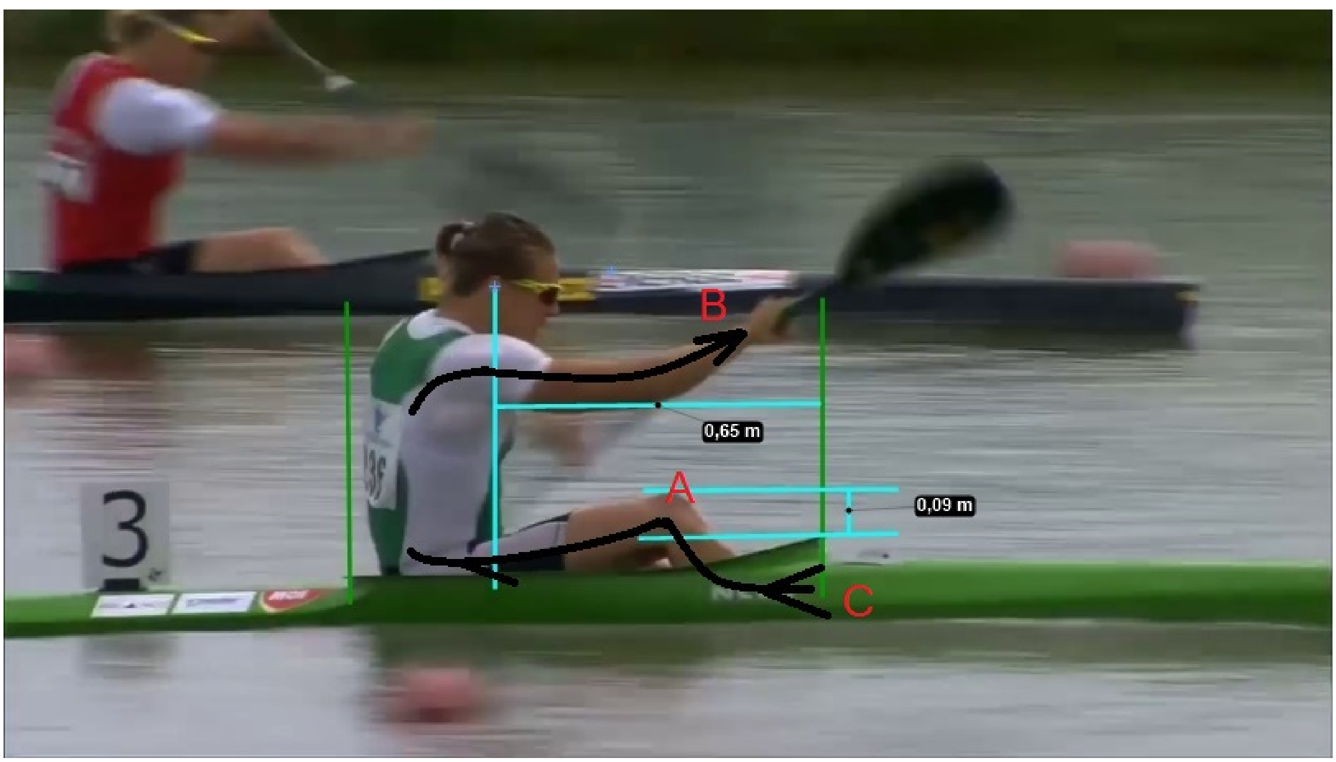
In **fig. 7.1.3** the athlete is entering the water. The left leg is already pushing without however moving; the counter-push leg is pre-loading and elastically fixing torso and pelvis. The knee (red-coloured letter 'A') is in line with the boat's centre-line, meaning that the foot is no longer in the traction stage, as it was in the previous frame. Before the knee is once again lowered, the blade is further into the water, firmly preloading (i.e., fixing) the entire chain of force transmission.

The force goes through each and every joint as it passes from the hands to the feet. The shoulder blades are fixed at this point, before the water's force increases. If this does not occur, athletes pave the way for failure in the shoulder blades or other parts of the body, as described in **fig. 5.2**.

Fig. 7.1.4 is a lateral view of the athlete as pictured in **fig. 7.1.2**, in exactly the same position. The height of her knee is 0.09m above the tip of the cockpit (red-coloured letter 'A'); the vertical projection of the middle of the ear is 0.65m from the projection of the tip of the cockpit. Point 'B' highlights the pushing action in the final active stage before exit. Point 'C' highlights the counter-push action (traction) performed by the right foot.

Similarly, **Fig. 7.1.5** is a lateral view of the athlete as pictured in **fig. 7.1.3**, in the same position. Despite the pressure on the footrest (point 'C'), the height of point 'A' remains the same (0.09m).

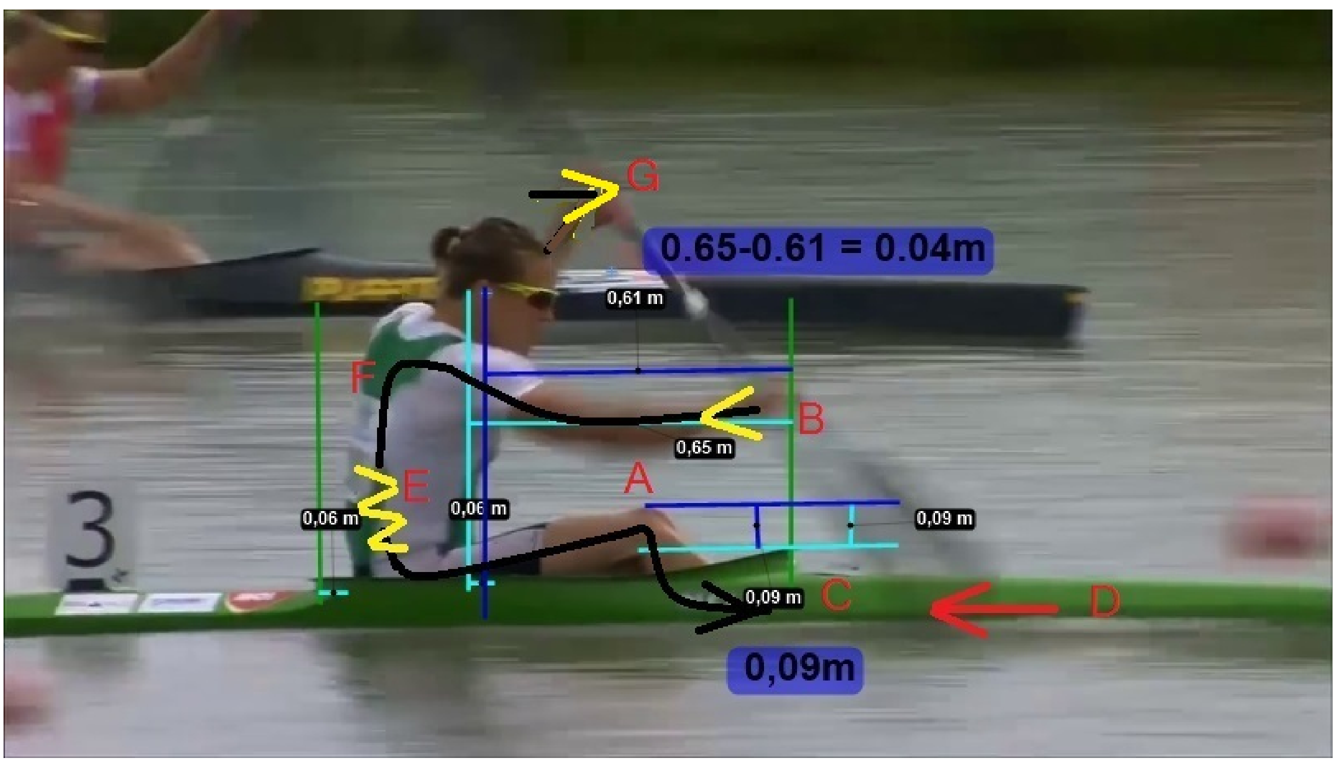
[Fig. 7.1.3]



[Fig. 7.1.4]

Given that in order to go from the counter-push stage to the pushing stage we would expect there to be at least 1cm of mechanical 'play', we would expect a height of 0.08m. Apparently, the fact that the torso moves forward by 0.04m allows the body to push through the pelvis and maintain pressure with the pushing leg without losing range. The angle of the pelvis will be further discussed at **para 8.1.1**. In both kayak and rowing, the pelvis angle affects the balance between the body's front and back muscles, which are preloaded and fixed in the middle of the aerial stage. The choice of angle between pelvis and torso and the preloading and fixing of muscles is performed when tension is at a minimum.

The athlete's pushing leg is therefore preloaded and ready for action before the blade even touches the water. The vertical projection of the ear is 0.61m (marked in blue) from the tip of the cockpit, corresponding to the ear moving forward 0.04m. The body's forward angular speed compared to the boat aids in balancing out of the foot's pushing force at point 'C' (approximately 7kgf), as well as balancing out of the torques applied at points 'B' and 'G'. To simplify, let's concentrate only on the force applied at point 'B'. As previously mentioned, the force applied in the first few hundredths of a second of the paddling motion is low and allows for muscle fixing (elastic preloading with very high stiffness) starting from the top (point 'F') before the transmission of force of the leg muscles happens at point 'E'. Before entry and during submersion the muscles of the leg exercising traction tighten (preload) and fix the torso's rotatores muscles marked at point 'E'. The final fixing action of the chain of transmission that commenced with the outer limbs (hands and feet) is performed at point 'E', and the athlete makes use of the torso's rotatores muscles that stabilise the pelvis (abdominal obliques, latissimus dorsi muscle in bilateral combination, etc.). At this stage, if the muscles of the shoulder girdle are not yet suitably fixed, there will be a powerful structural failure or stiffening.



[Fig. 7.1.5]

The force represented by point ‘D’ is the almost-constant water resistance that has to be balanced out by the force applied at point ‘C’. Therefore, the pushing force exercised by the right foot on the footrest (**fig. 7.1.5**) must begin the very second the paddle exits on the left side, unless it is performed using the seat of the boat, which would however delay preloading of the muscles of the pushing leg.

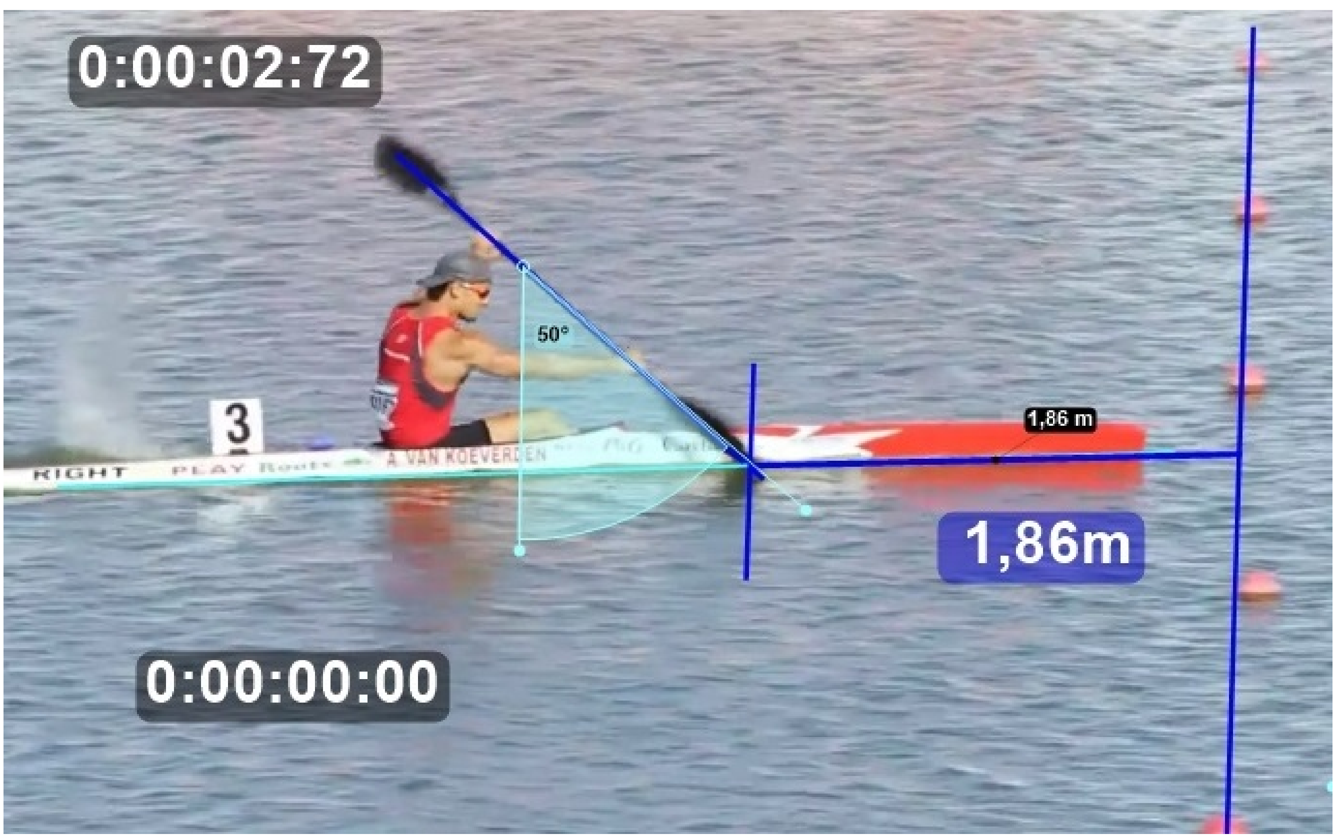
7.2 — The best course of action

We will now analyse the technique used by Adam Van Koeverden in the K1 1000m Finals A World Championship, Szeged 2011, which the athlete won with a considerable 3” lead. Van Koeverden’s is objectively the best technical execution of the race for the following reasons:

- The measurements taken contain no negative elements; and
- The data shown – like in the case of the Croatian M2x – is not analysed with a view to detecting mistakes, but actually taken as a reference point.

The race results are:

- 1st place: Adam Van Koeverden (CAN) 3:36.194
- 2nd place: Anders Gustafsson (SWE) 3:39.488
- 3rd place: Eirik Verås Larsen (NOR) 3:39.818



[Fig. 7.2a]

The race was carried out in conditions of headwind; the parameters measured according to Step 1 are therefore subject to a T100 value higher by approximately 1 second compared to other races.
As for **para. 5.1**, we will measure the Step 1 parameters (*05). In the present case the camera is not fixed and therefore length is measured in relation to the position of buoys.

Fig. 7.2a shows the point of entry in water (marked in blue), which is at a distance of 1.86m from the buoys. **Fig. 7.2b** shows the athlete in the middle of the paddle action (marked in green) and the distance from the buoys is still equal to 1.86m. **Fig. 7.2c** shows the athlete when exiting the water (marked in red), with a distance still equal to 1.86m. The top of the image shows a time of 3.07”: this time is used when the athlete ends the 50m segment used in the calculations. At the bottom of the image a time 0.35" is shown, representing the duration of the water stage.
The bottom of **fig. 7.2d** shows the time of stroke duration, equal to 0.55”.

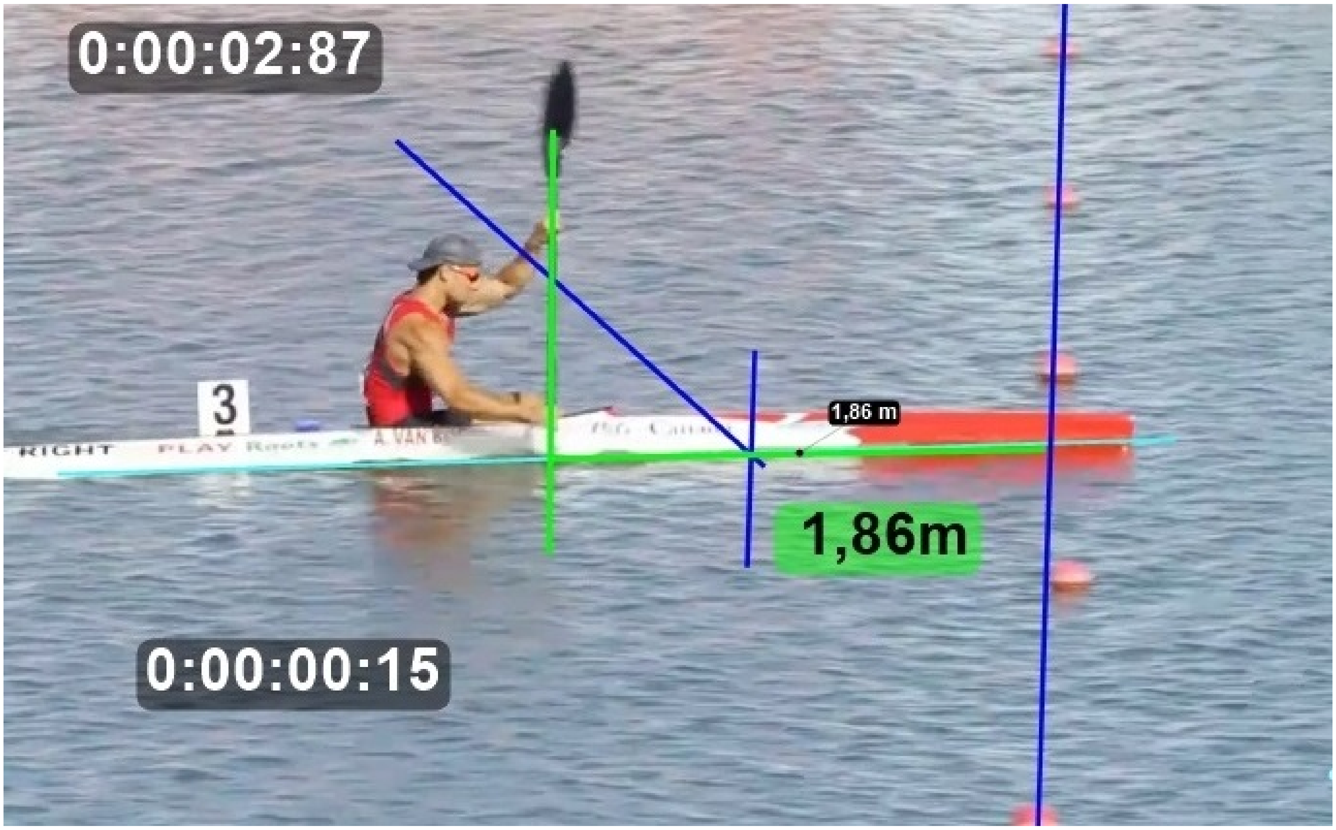
The measurements taken are as follows:

Angle of entry	= 50°
Angle of exit	= 55°
Total angle (TotA)	= 105°
Mid-stroke slip	= 0.00m
Total stroke slip	= 0.00m
Time in water	= 0.35”
Stroke time	= 0.55”

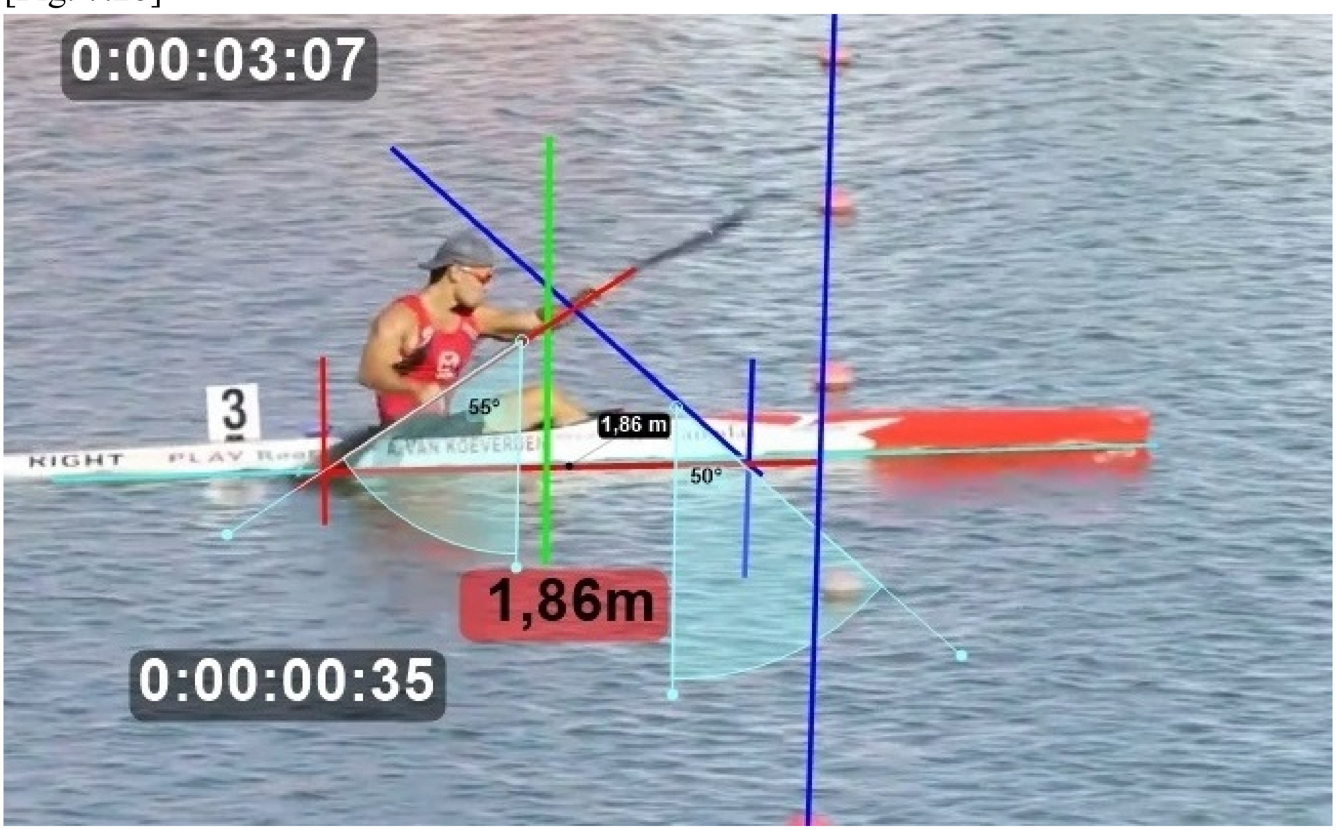
Once we have this data, we can use software to obtain the calculated parameters, which are as follows:

%tWater (% of time in water)	= 64%
%AirS/WatS (% air speed on water speed)	= 125%
Rate; stroke rate	= 109spm
T100m (time per 100m)	= 22.0”
Energy per stroke	= 152 Joules
Energy per stroke (hard water)	= 172 Joules
n100 (number of strokes per 100m)	= 40
Advancement; advance per stroke	= 2.50m
Stroke Radius1	= 0.87
Apparent Radius 1	= 0.87
Average force per stroke	= 61 N
Average force in water	= 95 N

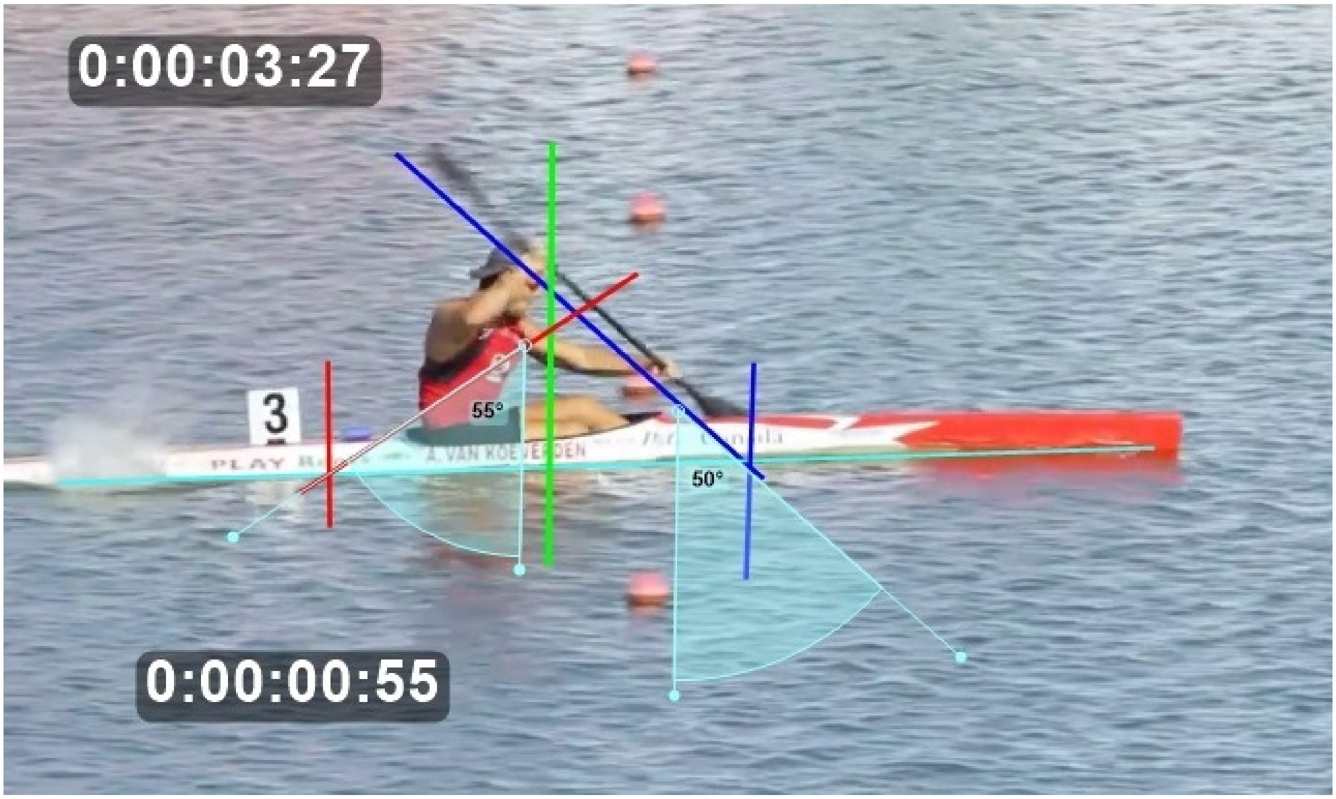
Fig. 7.2e shows the same type of image as at **para. 5.2** and **fig. 6.1e**. Contrarily to the previous examples, this one presents anomalies: the angular paddle speed is constant and equal to 15/0.05 = 300°/sec. This is due to a perfect equilibrium of inertial forces applied by the athlete on the equipment (boat and paddle), and through which he interacts with the water as if he were pulling from a fixed device.



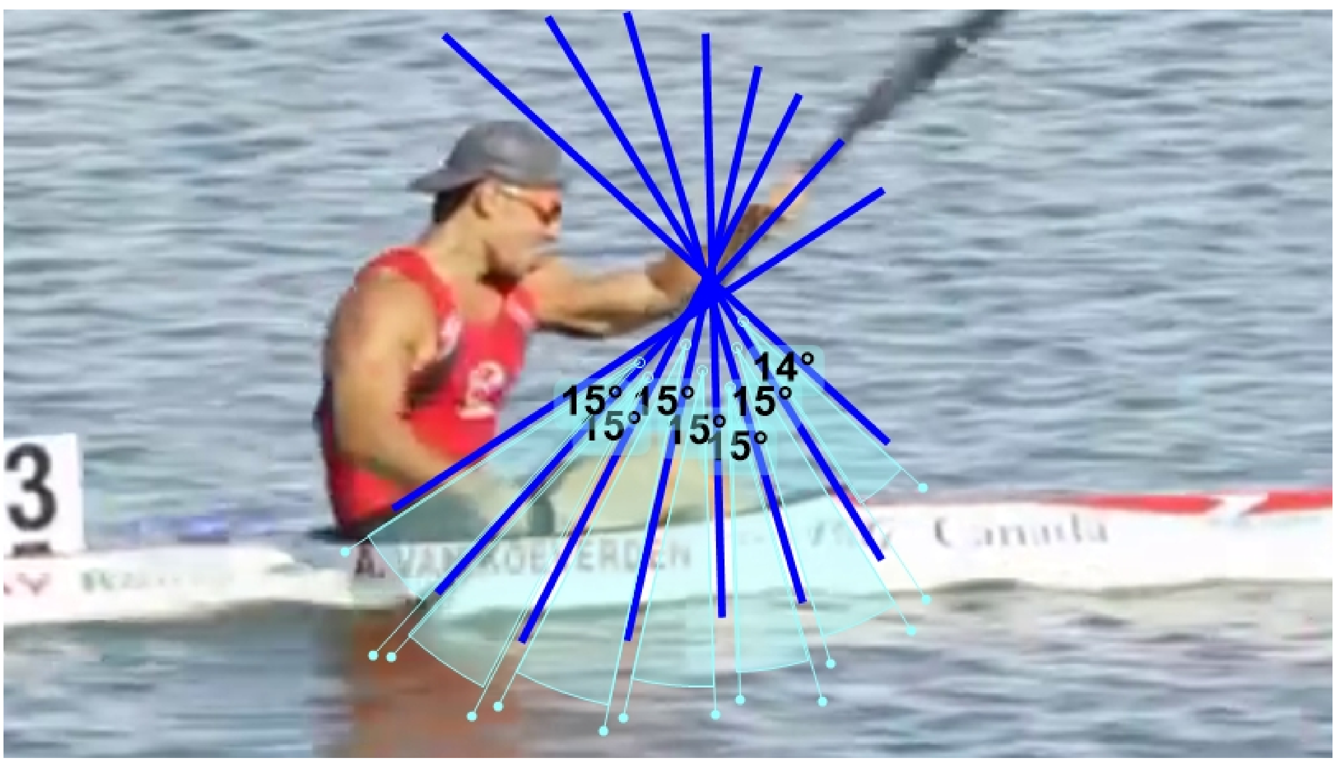
[Fig. 7.2b]



[Fig. 7.2c]



[Fig. 7.2d]



[Fig. 7.2e]

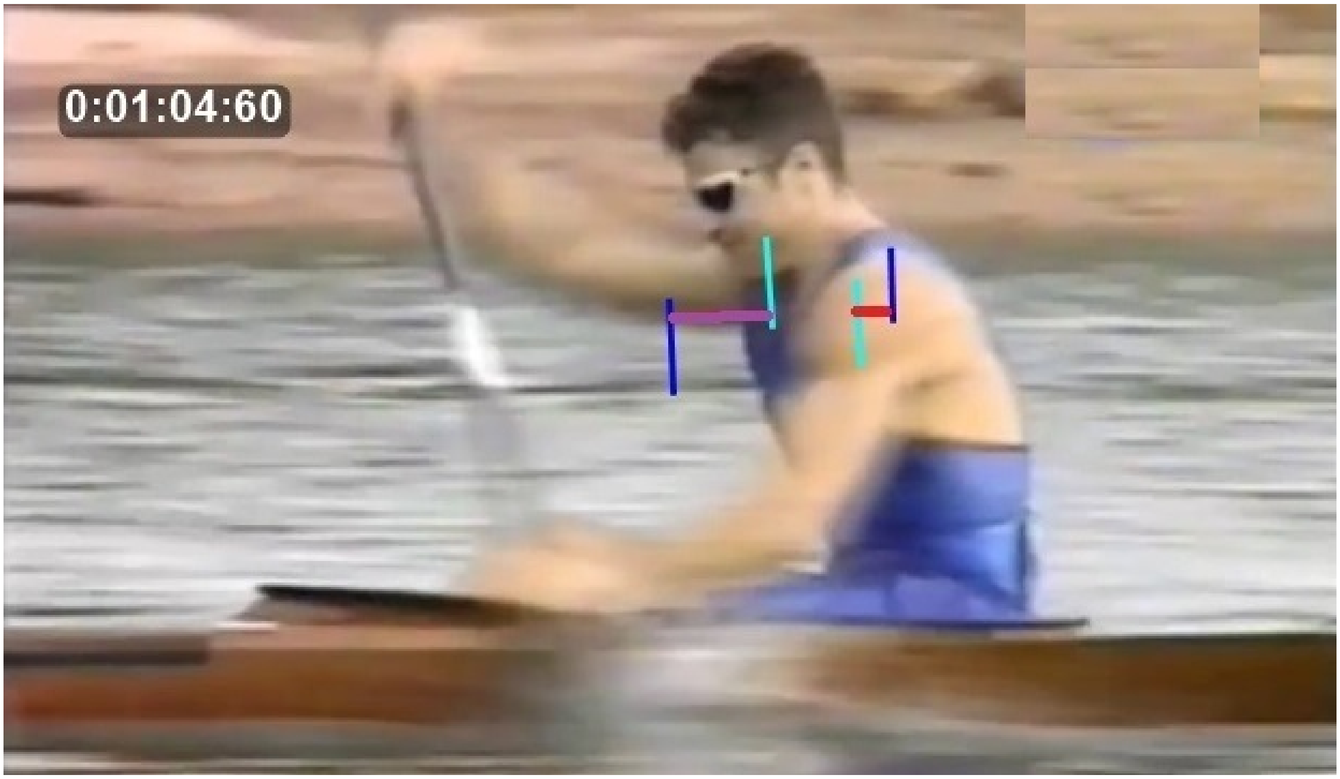
7.3 – Further examples

The following examples will show how easy it is to obtain useful information even with little to no effort going into data elaboration.

Figs. 7.3a and **7.3b** show athlete Antonio Rossi in the K1 M 500m Atlanta 1996 Olympic finals. We can once again notice the athlete's forward movement compared to the boat: the magenta-coloured line is longer than the red one.

The %tWater is 60%: the athlete appears to spend a lot of time in the air, but it is only an impression. Another element that is easily observed is the synchronicity of the movements of the athlete's legs. As we have previously seen with Tomicevic (**para 5.4**), at the moment of entry in water the pushing leg's knee is at the same height as the other knee, and therefore performs the same preloading and fixing action as the rotatores muscles. The movement performed by the traction leg's knee on the footrest (counter-push) begins before the water entry stage, whereas the movement of the pushing leg begins one frame (or 0.04") after contact with water, just the right amount of time to complete the activation and 'fixing' of the whole chain of transmission of force starting from the top. Many athletes use this type of synchronism: Walz's knees reach the same height as each other after another frame (a further 0.04" delay), meaning that at the entry stage Walz prefers to add some dragging motion, allowing him to save some time in water; his %tWater is indeed higher than Rossi's and equal to 66%. In the Olympic final won by Walz, the second-placed athlete Dostal's %tWater is equal to 60%.

Figs. 7.3c and **7.3d** show athlete Pimenta in action in the same K1 1000m Olympic final won by Walk (Rio 2016). Pimenta finishes in fifth place, 4" behind Walz, with a %tWater = 60%, and with no forward movement – indeed, at the moment of entry in water the athlete moves backwards compared to the centre of the paddle stroke.



[Fig. 7.3a]

[Fig. 7.3b]

[Fig. 7.3c]

[Fig. 7.3d]

Chapter 8: The Link Between Hydrodynamics and Mechanics in Kayak

This chapter will focus on the physics behind this paper, with a few examples on how it applies. For the calculations and images please refer to the previous chapters.

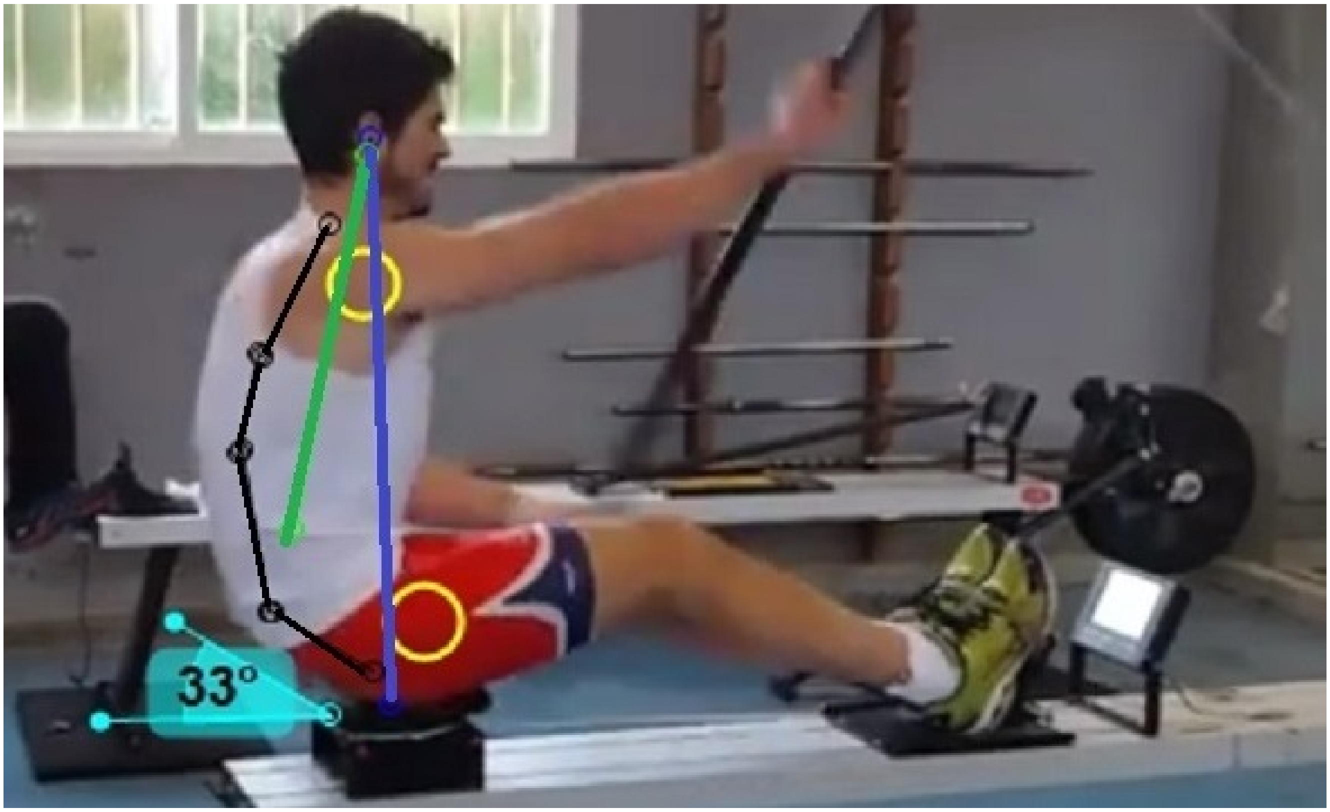
8.1 – Balance and Posture

Balance and posture are two very important elements, being the fundamental requirements for athletes, and must be constantly kept in check. Harmony, aquaticity, and sensitivity will be impaired if the athlete is afraid, and fear is deeply connected to balance and posture.
No calculation can tell us how to eliminate fear: in order to be time-efficient, trainers must simply come up with specific, tailor-made methods for each individual athlete. Taking amateur kayakers as an example, we can safely assume that, despite using easy-to-handle boats, their posture will result in tight core and pelvis muscles. Here, fear and joint tension are mutually dependent and can be eliminated simultaneously with the correct training exercised. Once the athletes' 'involuntary defence mechanisms' have been eradicated they will be ready for training. Should the problem reoccur it will be necessary to try alternative methods.
Once all the above problems are corrected, athletes will no longer have issues with balance and, surprisingly, will feel more comfortable on a higher seat. Often in such cases the seat is moved backwards – the following paragraph will look at the possible causes for this.

8.1.1 – Balance of Torques on the Pelvis

Fig. 8.1.1 shows athlete Roi Rodriguez (previously studied in **Chapter 4**) on an ergometer.
No criticism can be levelled at this athlete – he won the race analysed in **fig. 4.1** and his H-Graph corresponds to that of the Croatian M2x champions that I have referred to throughout this paper as the optimal case study (**fig. 2.1**).
Pictured here is the angle of the pelvis, regarded as an optimised individual value equal to 33° – one of the lowest values of this kind observed. Rather than looking at whether a different value could have yielded better results, let's concentrate on how we can use this value to improve our athletes' performance.

Athlete Brigitte Hartley (3rd place in the K1 500m W London 2012 Olympic Games), pictured in **fig. 8.1.2**, has, by contrast, one of the widest angles observed – although we do not have a precise measurement for this, the angle appears to be close to 90°.



[Fig. 8.1.1]

[Fig. 8.1.2]

Postural and angular elements are often ignored in kayak, and, moreover, the angle of the pelvis and that of the feet – both studied in the lateral view – are hidden. We will see that these are to be considered 'key angles' when dealing with posture. Additionally, whereas the angle of the scapulae has natural, pre-established fixing mechanisms, in almost every sport the balance of the angle of the pelvis is basically an art, something that must be learned. Therefore, if we were to define the 'cornerstone' of posture in kayak (and in rowing, also), it would be the adjustment and dynamic balance of these angles. The following elements depend on the values of these angles:

1. Transmission of force (Micro-Technique);
2. Control of the body's surge and pitch motions compared to the boat (Meta-Technique); and
3. Equilibrium of inertias on the side of the boat (as opposed to the same phenomenon on the propulsion side).

In rowing, due to the angle created by the feet and their positioning, there is the possibility of finding a standard setting. This is the opposite of what happens in kayak, even in multiple-person boats (K2, K4). Adjusting the footrest's tilt without being able to adjust the height of the traction support on the footrest (counter-push) is not enough – the height of the feet's push will nevertheless be restricted.

Let's, as usual, take the Sinkovic Brothers as our reference point, specifically in **fig. 8.1.3**, where they are positioned to enter the water (the frame has been taken from the video *Braća Sinković na Peruči i Rami 2015* – available on YouTube).

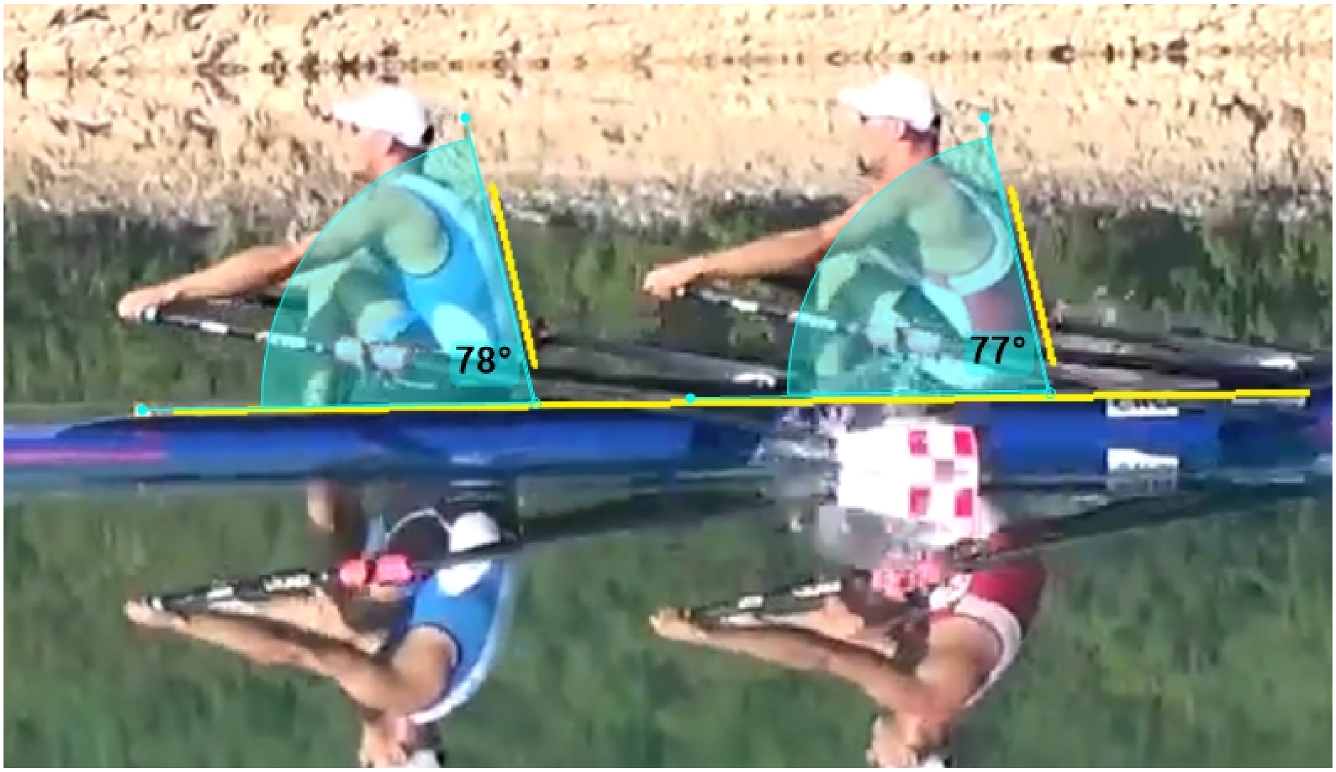
Without analysing the technique utilised, we can still observe that there is a long segment of the stroke in which the back maintains the same angular value compared to the boat, and this is obtained by balancing the front and back muscles of the legs.

Fig. 8.1.4 shows the moment when the legs' back muscles (green arrow) begin to prevail on the legs' front muscles (blue arrow), causing the pelvis to rotate around the hipbones (red line). As usual, we must distinguish between the 'invisible' phenomenon that we use as physical reference model for reasoning, and what little is visible to and appraisable by the naked eye, i.e., the angle of the back, which goes from 78° to 80°.

Therefore, trainers that rely solely on what they can see with their own eyes will only see the tip of the iceberg. Trainers who, instead, analyse the invisible parts will be able to 'see' even the rest. This type of analysis only needs to be conducted once, after which we can proceed on the basis of this first analysis.

The value of the angle of the back or that of the pelvis can seem arbitrary and unnecessary if we do not have a good idea of the functioning of muscular balance and all the other systems of equilibrium we have studied above.

In order to understand how to achieve optimal boat settings, we must go back to the previous example. In rowing, an angular positioning of the pelvis that differs from the usual will not force the athlete to adjust the position of the footrest; the trainer can still proceed to adjust it, but it is not an urgent matter with regards to the athlete's ergonomics. In kayak, however, altering the angle of the pelvis means that the footrest must be immediately adjusted relative to the seat, or the athlete will have to proceed with a different leg angle. Following this, trainers who want a more 'elongated' posture for their athlete's pelvis can simply move the seat further away from the footrest.



[Fig 8.1.3]

[Fig. 8.1.4]

Two further elements can lead to changes that will either improve or worsen the equilibrium of forces on the pelvis, and these are:

1. The height and tilt of the seat; and
2. The height of the feet's resting point and the height of the support needed to carry out traction (counter-push). This is a very important aspect because, if an athlete needs to decrease the height of the feet's resting point on the footrest – for the purposes of optimising the legs' push and relaxing the legs' back muscles – the height of the support needed to carry out traction (counter-push) must be adjusted. This, however, is not included in the standard adjustments in kayak, and may interfere with the tiller.

8.2 – The Force of Traction and of Acceleration in Kayak, Intra-Push

In a K1 M 1000m race the force necessary to tow a boat is roughly: Towing Force = 7 kgf (**Chapter 5**). The pushing force applied on the boat must balance the Towing Force constantly in all stages of paddle stroke.
However, since force can only be applied in the water stage:

WaterForce = TowingForce + AccelerationForce

where AccelerationForce (the force needed to accelerate both athlete and boat) represents the extra force that the athlete must to apply so that AverageForce = TowingForce .
This way, we set forth the conditions so that each stroke's speed is, on average, constant. On the other hand, the entire system – athlete and boat – undergoes continuous acceleration and braking with each stroke.
In order to simplify the calculations, suppose that in a stroke action the blade is submerged for the same amount of time as it is outside of the water. If so, WaterForce would equal TowingForce doubled, and therefore TowingForce = AccelerationForce.
More realistic data show that the percentage of time in water compared to total time, in the best case scenario, will be higher and equal to %tWater = 65%. With some simple calculations we can obtain the following results:

WaterForce	= TowingForce / 0.65 = 7 / 0.65	= 10.8kgf
AccelerationForce	= WaterForce – TowingForce	= 3.8kgf

The relationship AccelerationForce / WaterForce = 3.6 / 10.8 = 0.35 signals that the force of the acceleration stage that compensates the aerial stage is about one third of the total applied force. We shall see later on how, during races, athletes tend to choose a mode by which an AccelerationForce less than 0.5kgf is applied, and therefore the real optimal relationship is 3.3 / 10.3 = 0.32.
In the case of a %tWater = 50%, an average 14kg force will have to be applied in water. The relationship AccelerationForce / WaterForce = 7 / 14 = 0.5 shows that the force used to re-accelerate both boat and athlete is equal to half the total applied force. These two elements show just how damaging it can be to have a low %tWater.

How much force can be applied on the footrest? To make the calculations simpler, let us assume that %tWater = 50%:

1. The AccelerationForce = 7kgf is divided between the athlete's mass (80kg) and that of the boat and paddle (13kg) proportionally to mass, and therefore the athlete cannot apply on the boat a force lesser or greater than TowingForce + AccelerationForce * (13/93) = 8kgf. Should the athlete apply a force of, say, 12kg, there will be an excess force equal to 4kgf. This will cause the boat to move away from the athlete with an acceleration equal to 4 * 9.81 / 12 = 3.2m/s^2 (ignoring the opposite movement of the athlete's mass). With this acceleration, after 0.2" the athlete moves backwards with respect to the boat by a value Displacement = 0.5 * 3.2 * 0.2^2 = 0.064m, or 6cm. This is roughly what happens to athletes who dispel energy inwards (introvertedly) in friction internal to the system. This type of inefficiency is called intra-push. We will see how the opposite of this phenomenon (i.e. extra-pull) can be used in various ways, some better than others, depending on whether the rotational energy at the end of the stroke is used or not (**figures 6.1** and **7.1.5**).
2. When average WaterForce is 14kgf, the same amount of force is applied on the pushing hand, and double the amount on the hand exercising traction (although these figures are estimates, they are very close to real force values). The difficulty with kayak lies in applying an average force at the water stage of about 28kg on the traction hand, whereas the resulting force applied on the boat must be closer to 7kgf.
3. The problem with applying an 'average force in water' that is significantly greater than the TowingForce lies with the %tWater. Say, for instance, that an athlete has a %tWater = 25%; he would have to transfer 7kgf to the boat applying 56kgf on the traction hand (7*4*2). This way, the body itself becomes an 'energy bank'. Since the movement is cyclical the athlete should aim to take advantage of the energetic exchange between those elements that can store energy during the active stage and somehow return it in order to push the boat during the aerial stage. This is typical in oscillatory systems, and it is why the term 'harmonic' is used throughout this paper.

To summarise, the force applied in water can be minimal is the %tWater is high. The AccelerationForce, which represents that part of force that cannot be transferred to the boat during the active stage, is also the applied force that is the hardest to balance.

The most important consequences of this phenomenon are the following:

1. At the starting point, the boat is not moving and TowingForce = 0. For each 1kgf applied by one foot on the footrest, the other foot must immediately counter this action by applying an opposite 1kgf (counter-push) so as to create a torque that can balance out the torque on the paddle, and all the inertial and elastic elements of the chain of force transmission itself.
2. Training sessions with variable %tWater are carried out with different relationships between AccelerationForce / WaterForce. We as trainers must assume that athletes' technique will undergo variations, or else we may delude ourselves into thinking that we

are training strength in detail, whereas we simply risk modifying automated behaviours so as to only train the athletes' ability to accelerate.

3. Applying a hydrodynamic brake will reduce the boat's speed but the WaterForce may remain the same. This is of great benefit to the athlete as it weakens the AccelerationForce / WaterForce relationship.
4. For other reasons (for which I will omit showing calculations) the tailwind weakens the AccelerationForce / WaterForce relationship, and in this case we can go back to 'normal' by slightly lowering the %tWater. The opposite will happen in case of headwind.

As a consequence of the last two bullet points, strength training in water will be carried out, ideally, using a hydrodynamic brake and at the same time a reduction of the %tWater. It is possible to accurately calculate the ideal balance of the hydrodynamic brake and the %tWater:
For those readers wishing to skip the calculations below, the result is that, with a brake that increases the T100 (i.e., the time taken to travel 100m at a given speed) by 4", the athlete can lower the %tWater by 8%, thus maintaining the same AccelerationForce / WaterForce relationship.
This calculation is approximate and it is therefore advised to set it up so as to make it convenient to carry out. We can make the following assumptions: that an athlete's maximum speed at a rate of 100spm gives us a value T100 = 25", and that the limiting factor in this performance is the average force that he or she can transfer to the boat. In both cases, we have a TowingForce = 66N (**para. 5.1**), or approximately 6.7kgf. Going back to the example where %tWater = 50%, we know that with no brake the AccelerationForce = TowingForce = 6.7kgf. Since with a brake speed decreases by an amount equal to 21 / 25 = 0.84, the same happens with acceleration, and therefore with a brake the AccelerationForce becomes 6.7 * 0.84 = 5.6kgf. Now we can calculate the %tWater value that allows for the same amount of AccelerationForce that the athlete is used to under normal conditions. We know that with %tWater = 50% the AccelerationForce = 5.6kgf, and our goal is 6.7kgf. If we recalculate using 5.6kgf of TowingForce, AccelerationForce = 5.6 * 50 / new%tWater. If we invert this formula we will find that:

new%tWater = 5.6 * 50 / 6.7 = 42%

therefore the percentage of time in water is effectively lower than 8%.

The advantage of this type of training is, quite simply, that it allows athletes to apply maximum force in water over a longer distance. This is because speed and transferred power decrease by 84% compared to if there was no brake and, even from a physiological point of view, the 16% reduction in applicable power greatly aids the athletes' endurance.

Applying the hydrodynamic brake to the nose, rather than the tail, of the boat is highly recommended for those still attempting to improve technique. In addition to the psychological aspect of moving forward to push the added obstacle, in cases of minor imbalance due to athlete mistake the brake, if placed on the boat tail, tends to lower the it so as to make it more difficult for athletes to carry out cyclical motions.

If a boat is blocked – not too rigidly – by the trainer placing himself on a blocked and heavy boat (*04), the resulting situation will be the opposite of what we have at the start of a race, the only point in common being that both boat and athlete are almost stationary. Under these conditions the force applied in water is exactly the same as brake force, and the only element exercised is the athlete's ability to pull the boat without causing it to accelerate. In this phase the motion of counter-push is far less important and the athlete can apply to the pushing leg the same force applied on the hand.
As seen in the first four chapters, during the majority of stages of the race speed continually decreases. In the example at **fig. 1.1**, in the final 50m of the race athlete Lisa Carrington's T100 value goes from 19” to 20” in the space of 30m. When calculated, this results in a negative acceleration (i.e., a deceleration) of 0.05m/s^2. If we multiply this value by the standard mass that we use in all the calculations (80kg + 13kg), we obtain a force of 4.65N, equal to around 0.5kgf. This result allows us to understand what happens during the race:

1. In this case the athlete's %tWater = 55% (making it a borderline case as the values for all other athletes remain between 60-65%).
2. The TowingForce in that segment is around 7.4kg and WaterForce is 13.5kgf. Because of the deceleration the WaterForce becomes 13.0kg.

This shows that when athletes train at a constant speed they are not, hydrodynamically speaking, under the same conditions as they would be at the stage of the race where deceleration occurs. Athletes attempting to accelerate in the final 30m of a 200m race do the very opposite of what they should be doing, which is applying an alternative technique that gives more space to traction rather than acceleration, adapting to the fact that AccelerationForce decreases by roughly 0.5kgf.

For those wishing to take the time to verify this information, please consider the following example: the winners of the K2 M 200m 2014 World Championship were the SRB crew, with the GER crew coming in 2nd and the RUS crew in 6th place. Up to the 150m line these three crews were all within close distance of each other, but at this point the SRB crew took the lead – albeit by a small distance – and the two remaining crews attempted certain actions. The GER crew remained in 2nd place and, striving to move into first, its %tWater = 60%. The RUS crew finished the race in 6th place, 0.6” behind 1st place, with a %tWater = 55% – this happened because they attempted to accelerate when they should have simply been working on reducing deceleration, causing paddle slip in water. The slip reduces water time and the situation, already compromised at that point, kept getting worse since it becomes harder and harder to apply the average TowingForce required to maintain speed. What happens is we have an inescapable chain of events triggered by just one mistake, i.e., applying a technique that would otherwise be sound during the acceleration stage, but applying it at the wrong time, when athletes no longer have the strength to keep their muscles tight and to recover the energy used during the paddle cycle. As a consequence, the lack of inertial balance produces negative effects and the chosen technique (that is, to accelerate the boat) is bound to fail.

8.3 – Angular Sector in Kayak

Another fundamental aspect of both kayak and rowing is that the angular sector is quite large (more than 90°). Using longer levers in water and a smaller angular sector would make it harder to avoid blade slip in water – this is the case for boats used in the adaptive rowing TA (Trunk and Arms) and AS (Arms and Shoulders) categories, where athlete movement is limited and therefore the length of the oars and the openings between oarlocks must be reduced. This is similar to what happens in slower styles of kayaking (e.g. wildwater canoeing), where the paddles are shorter compared to those of sprint kayaking.

After entry, water around the blade is slowly rotating and the angle of incidence of the water on the blade will depend on several factors:

- Inclination of the shaft (that we can see in video clips shot from a lateral angle);
- Blade's elastic deflection;
- Body and boat surge and pitch motions; and
- Water motion around the blade, i.e., the way in which water entry (or 'water grip') has been carried out.

Basically, at the entry stage, the blade is submerged in motionless water. The blade then causes the water to rotate with a wide Radius. At this stage, athletes will be taking advantage of the 'hydrodynamic lift', and the tip of the blade moves forward compared to the initial point of contact with water.

In the middle of the traction stage the tip of the blade passes under the point of contact with water, moving backward with respect to it.

In the final stage of traction the blade interacts with the water that has been displaced in the previous stages. Thanks to the wide radius rotational movement (activated by keeping a high Radius1, **para. 5.1**) the water produces considerable equivalent mass upon which traction may be carried out. Finally, once again one can take advantage of the 'lift', and the tip of the blade begins again to move forward towards the initial point of contact with water.

If things do not go as smoothly as described above, a slip will occur, whether to a greater or lesser degree. This means that the optimal physical phenomena have not materialised. If this is the case, it will be pointless to keep attempting to duplicate the technique of champions – it will be necessary to do more than that.

8.4 – Oscillation in Kayak

As mentioned before, and as will be reiterated below, kayak is a cyclical sport in which kinetic and elastic energy either move from one element to the other, or are dispersed. Those readers hoping to receive immediately usable information may be disappointed by the preceding statement, but the physics of oscillating systems itself amounts to little more than a principle: *the principle of equipartition of energy.*

When discussing how to optimise transmission we looked at examples of minimal stiffness (Marko Dragosavljevic), and examples of high levels of stiffness. In both cases, it is necessary for the athlete to remain flexible (elastic) in order to be able to recover energy during the cyclical equipartition between kinetic and elastic energy.

We have seen that athletes who are more rigid carry out all the movements simultaneously the moment the blade enters the water, and this often causes them to lose ground due to the excessive stiffness that leads to an imperfect water grip. This effect is mitigated by the paddle's own elasticity, but the paddle cannot adapt itself to the various stages of the race.

The athlete's body will be oscillating whether the boat undergoes a pitch motion similar to that of a dolphin, or whether there is simply a surge oscillation. To better understand this concept, observe athlete Walz in the Rio 2016 Finals A K1 M 1000m: up to the 500m mark, he proceeds with a pitch only slightly lower than Kozak's (**para. 7.1**), whereas in the final 250m there is no pitch motion. To explain this without the use of mathematical models, we can use as an example a similar sporting phenomenon: in a 100m track and field flat race, athletes' bodies will not undergo any vertical displacement but should oscillate by about 5cm. In reality, the centre of mass moves in a vertical sense but the movement of the arms serves to fully and deliberately compensate this phenomenon.

Although it is impossible to prove from video footage that the body's oscillations are important, I can at least show what the results of poor oscillation are. When oscillation – even if it is invisible – is compromised, the transmission of energy between the body's various joints is interrupted.
Statistically, if there is no perfect equilibrium of inertias, a part of energy will end up being dispersed. If an athlete is satisfactorily carrying out transmission of strength with a muscle group and the remaining parts are suitably fixed, his or her muscles will absorb the dispersible energy, and will elastically recover the re-usable energy. If, on the other hand, one of the athlete's joints is too rigid or, rather, too unrestrained, the dispersible energy will damage the myofascial system. Either way, elasticity is reduced and the cyclical movement's energy flow is dispersed; in the second case, however, there will be an accumulation of problems that may limit further improvements later on.

Obviously, the extent of these energy transmissions must be balanced between the kinetic energy of mechanical oscillations and elastic oscillations. As we have seen, an athlete who succeeds in harmonising all actions and, at the same time, reducing these phenomena is Adam Van Koeverden (**para. 7.2**). However, he only manages to do so perfectly in the year 2011, and this suggests that it is due to the athlete's own talent combined with a series of events, rather than systematic technical training. On the other hand, the M2x CRO appear to achieve excellent results throughout the years, and crews that have the same trainer all show an excellent behaviour in terms of quality.

Chapter 9: The Ultimate Question

In any sport athletes must master technique to the point where it is perfect and it can be applied automatically in order to satisfy the necessary and sufficient requirements for achieving the predetermined goal. The question for trainers is the following: *Is the athlete that I am training capable of satisfying them?*

And, notwithstanding the athletes: *Do I, as a trainer, know what these necessary and sufficient requirements are? Or am I only familiar with Base Technique and a few other elements and proceed by just doing my best?*

Throughout the paper it has been shown that there is a definite link between technique, results and race behaviour, the latter measured by means of the H-Graph. Those who experience problems with technique cannot compete on equal terms with others; those who fail to compensate errors throughout the race will have a disastrous race behaviour and equally disastrous results, and cross the finish line several seconds late. Obviously, athletes who make mistakes and constantly fail to compensate them are the athletes we will never see in any finals.

All the time, the 'brain' or the 'mind' merely act to complicate things further. It is impossible to 'transform' athletes who have problems with technique into successful athletes only by solving the problems associated with their mind and by ensuring that they 'put their mind to it' or 'pour their heart into it'. Quite simply, athletes who have problems with technique will also face additional difficulties with issues related to the 'mind', since their brain will be overloaded with errors that need compensating and strategies that should be used to deal with unforeseen adversities.

Technique is not only a list of movements and advice (Base Technique): it is the specific aim of sport (both external and internal, Meta-Technique and Micro-Technique). It is the basis upon which we evaluate athletes' qualitative abilities.

All qualitative abilities that are useful in kayak and rowing are impossible to be measured directly – it is not about length, or weight, or timing. In physics these types of qualities are known as non-dimensional, for example:

- An angle;
- A force relative to weight; or
- Synchronicity of time, defined as a percentage of the total duration of the movement or as an angular sector of a 360° cycle.

The elements of Meta-Technique are therefore non-dimensional, and so are the elements of Micro-Technique. All elements that are linked to the qualitative aspects of athletes are, ultimately, relative. The quantitative side of things – 'hard' training – is second to this, and, before starting serious training trainers must ask themselves: *Based on the athlete's abilities, should he or she engage in this to the fullest extent?*

Young athletes are often recruited in schools; the ones selected are those who are best at expressing their power on an ergometer. How can we ask them the right question? How can we ask potential athletes, ones who succeeded without however possessing any of the qualities required later on, that they must forget everything they have learned up to now and start from scratch? If we are unable to ask the right question to begin with, we cannot complain about facing serious problems later on.

We have seen the importance of using Meta-Technique and Micro-Technique to perfectly carry out actions, and must check with prospective athletes to see whether they would enjoy this kind of game: it is not about throwing our athletes head first into arduous training, but more about letting them play with the water with a view to ultimately building up to the correct movements. It is like climbing a mountain, but not just any mountain. What matters is not how long it takes to climb it – many athletes reach their athletic peak after 10 years of activity – what matters is ensuring that it is the highest possible mountain one can climb. If it is not, athletes will incur in those catastrophic results that we have seen in the previous chapters, even within athletes participating in international races, that is, they try using race tactics that they are unable to implement due to their imperfect technique; they may be placed right next to a champion, and possess all the strength necessary to pass him, but nevertheless lack the technique to do so.

Conclusion

We must distinguish between the following three elements: technique, the purpose of implementing technique, and the particulars of how it is implemented.
As a trainer myself, I usually invite my athletes to change one element of technique at a time, and to do so in quick succession and deliberately, while at the same time keeping my eye on a specific physical phenomenon. After that I only give athletes ‘positive feedback’ about the physical phenomena that they themselves are unable to assess, until it is no longer necessary. Athletes must, first, achieve their purpose in a simplified way, improving little by little each time their implementation of technique, and, second, make it so motions come automatically, without having to think about them, in order to keep a clear head for the purpose of tackling training or the next ‘technical’ problem.
In every sport, an athlete’s technical growth will be faster if he or she has a champion to imitate during daily training. This is the fastest and most efficient way to train athletes if trainers do not have the time to systematically follow an individual athlete’s training path. It is also a method that allows any trainer to train even an entire team just by having one good athlete to imitate. There are downsides, however: in addition to the risk of making mistakes when attempting to imitate the champion’s actions, this method is also not suitable for training crews. Within a crew it is impossible for each athlete to freely express their automated actions, and these actions will vary significantly depending on their position on the boat. Using this method, trainers may at first save a lot of time, but once they have moved the athletes around in order to find the best combination, they will be left in difficulty and without knowing what to do.
With regards to the methods of evaluation provided above, these help us to highlight the differences between skilled and lesser-skilled athletes. A difference of 2cm or 4cm in the position of the torso may seem arbitrary and unrelated to technique; and yet it is an element that, more so than others, displays the substantial difference between more technically skilled athletes such as Van Koeverden and Walz, and athletes who are more athletically gifted such as Hoff and Dostal. It is up to trainers to fully comprehend the information provided by the present paper and to then use it to solve problems.
Behind all the graphical methods of evaluation shown in this paper is the theory of hydrodynamic propulsion, and the related elements of Meta-Technique discussed throughout. The assessments carried out use the analysis of video footage to highlight traces, but the phenomena considered remain invisible to those who are not fully aware of their existence.
Simplifying Meta-Technique by getting rid of fundamental elements – for instance by using an excessively stable, or even fixed, boat – will lead to no significant results. Training out of water (like paddling standing up or in the air) is only useful to the extent of teaching athletes the technical jargon and to build on the idea that the next element can be set up on the basis of

correct and automatic behaviours.

Using methods with Meta-Technical requirements that are too advanced for certain athletes – such as an excessive Radius1, 2, or 3, or %tWater, or a hydrodynamic brake placed on the boat tail rather than on the boat nose – may increase the magnitude of certain problems instead of solving them. The best course to follow is to train by alternating between difficulties and facilitations, using contrasting exercises so athletes can find the right balance in the chosen techniques.

Finally, to get an idea of how training carried out in a systematically different way can become an important means of assessment, imagine an athlete racing three times along a 100m segment:

- The first time, with little to no warm up;
- The second time, following a good physical preparation; and
- The third time, following all the necessary strength and/or postural training.

The result will be different for each type of athlete:

- Perceptive athletes with low stiffness will immediately obtain the best results;
- Athletes with high stiffness will obtain their best results in the second round;
- Athletes who are unable to fix and protect the weakest links of the chain of force transmission will obtain their best results in the third round.

Once we know which 'type' of athlete they are, we will be able to concentrate ourselves on the their individual characteristics without wasting time on what they are already capable of doing.

Moreover, the information regarding the three types of athlete is crucial when forming a crew:

- Because it is essential to carry out a warming up preparation that works for each and every crewmember; and
- Because, based on individual characteristics, the paddle's stiffness should be chosen so as to balance the differences in muscle stiffness among athletes. Measuring paddle stiffness only requires a few minutes, and will allow us to choose paddles with different levels of stiffness even among a set of new, apparently identical paddles. Older paddles tend to have lower stiffness values.

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