# BIOMECHANICS OF PADDLING

**John Baker**

**AIS Movement Science, Australian Institute of Sport, Canberra, Australia**

Sprint kayaking performance is based around the simple premise of maximising propulsive forces while minimising drag forces. In a race it is an uncomplicated matter of whoever crosses the line first, i.e. has the highest average velocity, wins. Underlying these straightforward foundations is a number of complex mechanical interactions. Included in these are hydrodynamic drag and propulsion; force development and technique of the paddler; and interplay of the paddler and kayak. Added to this are the kayak classes of K1, K2, and K4 where in the multi-person craft the mechanical system gains further complexity. This presentation will explain the practical implications of the influences on mechanical system and from there outline various methods to evaluate paddling technique and performance with practical application of these analyses.

**KEY WORDS:** kayaking, technology, force.

**INTRODUCTION:** At the 2012 London Olympics Flatwater Canoeing events will be held over 200m and 500m for women and 200m and 1000m for men. It is the first time the 200m event will have been contested at the Olympics Games. Based on the time demands sprint kayaking is a power/endurance sport that relies on the athlete's ability to generate and transfer force through the paddle and boat to propel the kayak. The aim of sprint kayak racing is to cross the finish line in the fastest possible time. In order to achieve this, the athlete must produce and maintain the highest average kayak velocity in comparison to all other competitors in the race. A number of factors affect performance in sprint kayak racing including technique; strength; boat movement; boat parameters; paddle design environmental factors such as wind, current and temperature; boat parameters; and paddle design.

**DETERMINANTS OF KAYAK PERFORMANCE:** To move a kayak forward the paddler must generate enough propulsive force to overcome the drag forces acting on the boat (Millward, 1987; Baudouin & Hawkins, 2002). From a mechanistic perspective kayak acceleration is proportional to the net force acting on the boat with net force being determined by the following:

$$F_{Net} = F_{Propulsive} - F_{Drag}$$

The kayak paddle transfers blade forces from the paddler to the water and hence to the kayak via the footbar and seat (Michael, Rooney & Smith, 2009). That is the paddler applies force against the water through the paddle blade which results in forward movement of the kayak (Michael, Rooney & Smith, 2009). Blade force is a combination of drag and lift forces acting parallel and normal respectively to the direction of the blade motion (relative to the water) (Jackson, 1995). Propulsive forces are determined by the drag and lift forces generated by the blade when in water and how these forces are transmitted to the kayak through the paddler's seat and footbar though there is debate on the proportion each force contributes to boat propulsion (Sanders & Baker, 1998).

Boat drag forces are a combination of hydrodynamic and aerodynamic drag. Hydrodynamic drag is the highest contributor of drag forces which in itself consists of three components being wave drag, form drag and surface drag (Millward, 1987; Jackson, 1995; Baudouin & Hawkins, 2002).

**ANALYSING KAYAK PERFORMANCE:** While from a mechanical perspective sprint kayaking performance seems a relatively straight forward equation the ability to measure, analyse and make practical recommendations is a far greater task for the coach and biomechanist. Sprint kayak racing performance has been assessed with a variety of methods ranging from simply measuring the time taken to complete a given distance and calculating the average boat speed to more complicated force testing systems. Variables such as boat speed, stroke rate and race split times are simple to measure and are useful indicators of performance (Figure 1). Comparison to the paddler's past performances or other paddlers can be beneficial using this method. However, these variables do not always provide an indication as to how the paddler's performance has been achieved.

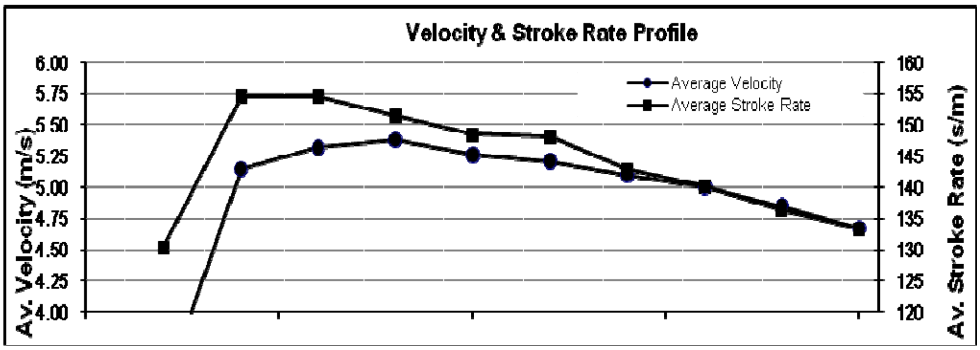


**Figure 1: Stroke rate & velocity profile for a WK1 200m paddler.**

For more detailed analyses additional measures need to be taken especially when dealing with elite paddlers. To gain an understanding of paddle movement and the possible contribution of lift and drag to boat propulsion 3D kinematic studies (Figure 2) have been performed (Sanders & Kendal, 1992; Baker et al., 1998). This data can be used for CFD and flow tank analysis but as yet it is unclear on the relative contribution of each component of force.

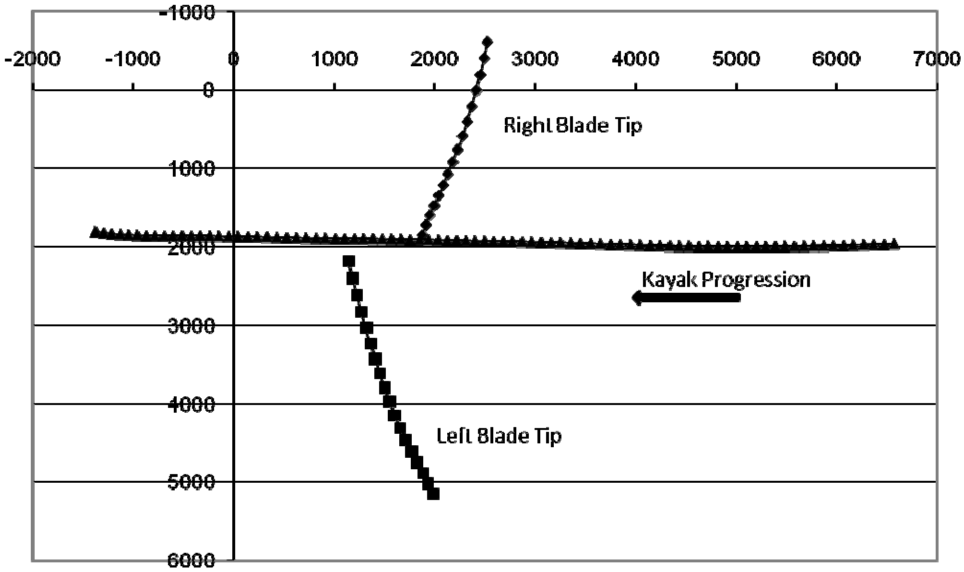
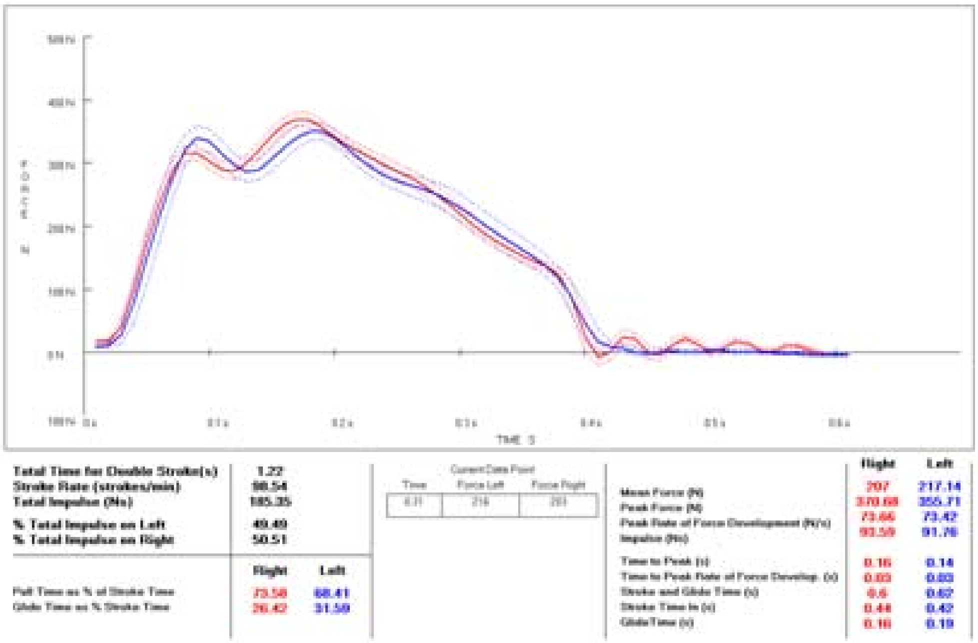


**Figure 2: Blade tip path relative to boat centre movement in the transverse plane. Data from Baker et al. (1998)**

Force and impulse generated by the paddler is a valuable assessment tool as it provides data in a task representative situation (Stothart, Reardon, & Thoden, 1987). During the kayak stroke, force is transferred from the athlete through the paddle shaft to the water, generating propulsive force. This propulsive force is responsible for propelling the kayak and generating boat speed. The amount of force and impulse (Figure 3) influences the boat speed generated by the paddler (Baker, 1998). A number of studies have analysed kayaking performance in non-competitive or training environments (Stothart, Reardon & Thoden, 1987; Aitken & Neal, 1992; Baker et al., 1999; Michael, Rooney & Smith, 2009; Brown, Lauder & Dyson, 2010; Sturm, Yousaf & Eriksson, 2010). ICF rules prevent instrumentation being used in actual races so inference from simulated race testing is often needed. While earlier work (Baker, 1998) has shown there is a strong relationship between simulated race distance time, and peak force and impulse it is not the only measure of importance. Current force systems only measure how much force a paddler pulls on the paddle shaft with no respect to direction. As such measuring boat acceleration at the same time as pulling force is invaluable for gaining an understanding of the effectives of the pulling force (Figure 4). Indeed acceleration measurement alone can provide an indication of left/right imbalances albeit with less technical indication.



| | |
|---|---|
| Total Time for Double Stroke(s) | 1.22 |
| Stroke Rate (strokes/min) | 98.54 |
| Total Impulse (Ns) | 185.35 |
| % Total Impulse on Left | 49.49 |
| % Total Impulse on Right | 50.51 |

| | Right | Left |
|---|---|---|
| Pull Time as % of Stroke Time | 73.58 | 68.41 |
| Glide Time as % Stroke Time | 26.42 | 31.59 |

Current Data Point

| Time | Force Left | Force Right |
|---|---|---|
| [illegible] | [illegible] | [illegible] |

| | Right | Left |
|---|---|---|
| Mean Force (N) | 207 | 217.14 |
| Peak Force (N) | 370.68 | 355.71 |
| Peak Rate of Force Development (N/s) | 73.66 | 73.42 |
| Impulse (Ns) | 93.59 | 91.76 |
| Time to Peak (s) | 0.16 | 0.14 |
| Time to Peak Rate of Force Develop. (s) | 0.03 | 0.03 |
| Stroke and Glide Time (s) | 0.6 | 0.62 |
| Stroke Time In (s) | 0.44 | 0.42 |
| GlideTime (s) | 0.16 | 0.19 |

**Figure 3: Left and right force curves for a K1 paddler.**

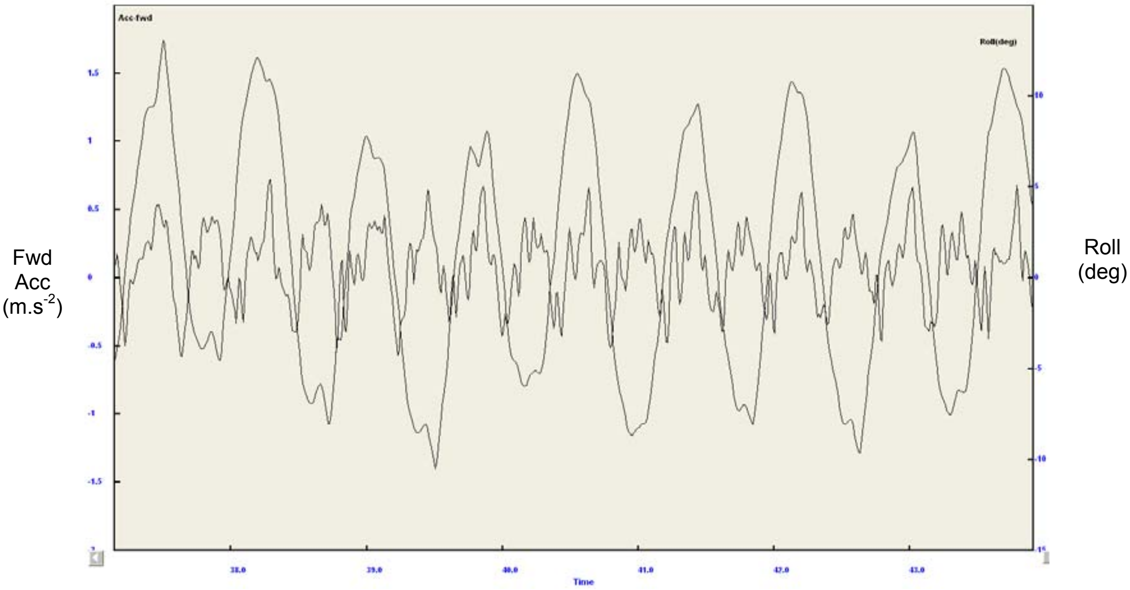


**Figure 4: Forward acceleration & boat roll a K1 200m paddler.**

Surface drag and to a far lesser extent wave drag are the two main forms of hydrodynamic drag which negatively impact on a kayak's movement (Michael, Rooney & Smith, 2009). The magnitude of boat movement during the kayak stroke directly influences surface and wave drag. Studies from rowing using gyroscopes determined the range of yaw and roll had a greater negative influence on boat velocity than did pitch (Wagner et al., 1993; Loschner et al., 2000) due to the larger effect on the boats wetted surface area yaw and roll have. While as yet no studies have determined the equivalent influence in kayaking given the similarities in boat shapes and velocities the same conclusions can be drawn. Minimising boat movement is the logical inference here, but the mitigating aspect of this argument here is that high forces and impulses are needed to propel a kayak while at the same time these factors will also create greater boat movement. Somewhere there is a trade-off and highlights the need for individual analysis within the spectrum of identified necessary performance criteria.

**CONCLUSION:** On paper kayak performance is a relatively straight forward biomechanical relationship. However when the real effects of a paddler sitting in a boat trying to race eight opponents are added then the situation becomes far more complex. Current methods of testing of can provide information rich analysis, but it is vital this analysis remains relevant to the individual paddler and coach. Identified influences on performance need to be considered in the first instance and these don't necessarily have to be complex. The rich tapestry of kayaking analysis is an interesting field and one requiring further investigation, not only from a straight biomechanical perspective, but also using evidence based motor learning principles to make long lasting changes to performance (Abernethy, 2012).

**REFERENCES:**

Abernethy, B. (2012). Personal Communication.

Aitken, D. A., & Neal, R. J. (1992). An On-Water Analysis System for Quantifying Stroke Force Characteristics During Kayak Events. *International Journal of Sport Biomechanics*, 8(2), 165-173.

Baker, J. (1998). Evaluation of biomechanic performance related factors with on-water tests. In J. Vrijins (Ed.), *International Seminar on Kayak-Canoe Coaching and Science - International Seminar on Kayak-Canoe Coaching and Science* (pp. 50-66). Gent: University of Gent Press.

Baker, J., Rath, D., Sanders, R. H., & Kelly, B. (1999). A three-dimensional analysis of male and female elite sprint kayak paddlers. In R. H. Sanders & B. J. Gibson (Eds), *Scientific Proceedings of the XVII International Symposium on Biomechanics in Sports* (pp. 53–56). Perth, WA.

Baudouin, A., & Hawkins, D. (2002). A biomechanical review of factors affecting rowing performance: A review. *British Journal of Sports Medicine*, 36, 396–402.

Brown, M. B., Lauder, M. & Dyson, R. (2010). Activation and contribution of trunk and leg musculature to force production during on-water sprint kayak performance. *Proceedings of XXVII International Symposium of Biomechanics in Sports,*203-206.

Jackson, P. S. (1995). Performance prediction for Olympic kayaks. *Journal of Sports Sciences*, 13, 239–245.

Loschner, C., Smith, R. M., & Galloway, M. (2000). Intra-stroke boat orientation during single sculling. In Y. Hong & D. Johns (Eds.), *Proceedings of the XVIII International Symposium on Biomechanics in Sports*. (pp. 66–69). Hong Kong: The Chinese University of Hong Kong.

Michael, J.S., Smith, R. & Rooney, K.B. (2009). Determinants of kayak paddling performance. *Journal of Sports Biomechanics*, 8, 167-179.

Millward, A. (1987). A study of the forces exerted by an oarsman and the effect on boat speed. *Journal of Sports Sciences*, 5, 93–103.

Sanders, R., & Baker, J. (1998). Evolution of technique in flatwater kayaking. In V. Issurin (Ed.), *Science and Practice of Canoe/Kayaking High Performance Training - Science and Practice of Canoe/Kayaking High Performance Training* (pp. 67-81). Tel Aviv: Elite Sport Department of Israel.

Sanders, R. H., & Kendal, S. J. (1992). A description of Olympic flatwater kayak stroke technique. *Australian Journal of Science and Medicine in Sport*, 24, 25–30.

Sperlich, J. (1995). Biomechanical considerations on possible performance improvements through boat and paddle in canoe sport. *Unpublished Translation: Australian Institute of Sport*, 1-10.

Stothart, J. P., Reardon, F. D., & Thoden, J. S. (1987). A system for the evaluation of on-water stroke force development during canoe and kayak events. *Proceedings of ISBS Biomechanics in Sports III & IV*, 146-152.

Sturm, D., Yousaf, K., & Eriksson, M. (2010). A Kayak Training System for Force Measurement On-water. *Proceedings of XXVII International Symposium of Biomechanics in Sports,* 712-713.

Wagner, J., Bartmus, U., and de Marees, H. (1993). Three-axes gyro system quantifying the specific balance of rowing. *International Journal of Sports Medicine*, 14, S35–S38

*In Memoriam*
This paper is dedicated to the memory of Dr Jurgen Sperlich, a great friend and mentor.

*Acknowledgement:* The author would like to thank David Aitken (AIS), Dr Jake Michael (NSWIS), Dr Adam Hunter, and Alexi Sachlikidis for their assistance in preparing this paper and presentation.