SUMMARY

Rowing performance can be judged by a single variable; the rower or crew that has the highest average boat velocity obviously is the best performer. While this clearly states the obvious, the processes that result in average boat velocity deserve investigation. During a race, rowers produce a large amount of mechanical power. For optimal performance, the fraction of this mechanical power contributing to average boat velocity should be maximal. However, power is inevitably lost. About 20% of the net mechanical power production is lost at the blades, where water is put in motion during the push-off. Another 5% of the net mechanical power production is lost to fluctuations in boat velocity.

In this thesis the mechanics and energetics of competitive rowing is investigated and discussed. Subject of these investigations are both the biological system, the rower as the engine of the boat, and the mechanical system of boat and oars.

Chapter 2 reports a study in which the effect of stroke rate on the production and distribution of mechanical power is investigated. It was found that at increasing stroke rates, power production as well as the overall efficiency increases. At increasing stroke rate, a slight decrease of \( e_{\text{velocity}} \) as well as a large increase of \( e_{\text{propelling}} \) is reported. Power production increases because the work per stroke appeared to be relatively invariant between all stroke rates. Propelling efficiency increases because the work at the blades is reduced with increases in stroke rate. Velocity efficiency decreases because of the larger magnitude of the accelerations of the rower that occur at increasing stroke rates, causing larger accelerations and decelerations of the boat.

Chapter 3 addresses the assumption that at increasing stroke rate \( e_{\text{gross}} \) will decrease. This would suggest that rowers perhaps should adjust their boat setup or technique in such a way that the amount of mechanical work per stroke is maximal, thus allowing them to row at low stroke rates while keeping a high power output. However, it was found that the ratio between energy consumption and production is in fact invariant with respect to stroke rate. In other words, stroke rate and gross efficiency were found to be unrelated. The implication of this finding is that the choice of stroke rate for rowing competitions is unlikely to be related to its effect on \( e_{\text{gross}} \).

Chapter 4 reports about the investigation of the effect of applying a mechanical constraint on the maximum mechanical power production on a rowing ergometer. Analogue to clip-in pedals in cycling or spikes in track running events, enforcing a constraint in such a way that the normal movement can still be executed can either
have a beneficial effect, or in the worst case have no effect on performance. It was found that by tying the rower to his seat by means of a simple strap, and thus preventing any vertical motion of the rower’s buttocks, rowers are able to produce up to 12% more mechanical power. This translates to a benefit of 2 to 3 meters after the first 10 seconds of the race for a rower that is attached to his seat.

**Chapter 5** addresses the relation between technique and the distribution of mechanical power in rowing. In the chapter, the relation between movement execution and $e_{\text{velocity}}$ is discussed. It was found that a good coordination between forces exerted on the foot stretcher and on the handle is important in minimizing power losses to velocity fluctuations. By means of a regression analyses, Chapter 5 points out that good rowers not only can produce a high mechanical power and have a high maximum oxygen uptake, but that they also have a good technique, at least in the sense that they can keep the inevitable velocity fluctuations as low as possible.

**In Chapter 6**, the power losses at the blades get a closer look. Custom made sensors allowed measurement of forces acting parallel to the blade. Besides blade forces, the deformation of the oar was reconstructed as well. It was found that neglecting the parallel blade force component in the calculations lead to a substantial underestimation of the estimated energy losses during the push off. It was also found that estimated energy losses did, on average, not depend on assumptions on the rigidity of the oars. Reconstructed kinematics were however substantially different when oar deformations were taken into account. In this chapter it was shown that in future investigations on blade dynamics, oar deformation or parallel blade forces should not be neglected.

**In chapter 7** the conclusions of this thesis are presented. It is stated that the aspects of the mechanics and energetics of rowing that are covered in this thesis can explain differences in performance between different rowers. However, it is also stated that many aspects of the mechanics and energetics of rowing are still not fully understood. For instance the effect of strapping the rower to his or her seat on performance has to be examined for on-water rowing, as well as for rowing efforts of a longer duration. Despite the findings described in chapter 6, the hydrodynamics at the blades are still poorly understood. A collaboration with a research group that has expertise in this field of research seems a good idea for further investigations.

To be able to find the optimal rowing technique - i.e. the coordination pattern that results in the highest average boat velocity over the race distance - a forward dynamics approach is suggested. By building reliable models and subsequently 'tweaking' parameters of this model a sensitivity analyses can be performed. Studying the
effects on performance could provide indications to what aspects of rowing technique researchers, rowers and coaches should spend their time on.

This thesis concludes with the statement that despite known existing fields of tension between sport practice and research labs, applied sport research such as described in this thesis should be continued and where possible intensified. Integrating sport into research and vice-versa will yield favorable results for both parties. Therefore, one should strive for both good research and good performance, ultimately resulting in publications and medals.