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Balance and control of a rear-wheel steered speed-record recumbent bicycle

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Abstract

The goal of the Human Power Team from the TU Delft and the Free University of Amsterdam is to break the world speed record in unpaced cycling (Sam Whittingham, 133.28 km/h). The design of such a faired recumbent bicycle is a challenge. The Delft design, called VeloX (Human Power Team (2013)), is a fully-faired monocoque front-driven recumbent bicycle, with minimized air drag and maximized space for a big and strong athlete. However, front driven bicycles have the disadvantage that the front driving induces unwanted steering and that the frontal area of the bicycle cannot be reduced any further. A solution would be rear-wheel steering. A common thought is that a rear-wheel steered bicycle cannot be laterally self-stable, and therefore hard to control. However, recent research (Knoll *et al.* (2012)) has shown that one can design a rear-wheel steered bicycle which shows a stable forward speed range.

Based on these results a rear-wheel steered recumbent bicycle has been designed, within the existing design constraints. Although not self-stable, this design shows a mildly lateral unstable behavior in the desired forward speed range of 0 to 40 m/s (0 to 144 km/h). Computer simulations demonstrate that the bicycle can be stabilized by adding a human controller model (Schwab *et al.* (2013)) to the bicycle model. For a set of expected lateral perturbations (side wind perturbations) it is shown that rider steer torque stays within human bounds, both in magnitude and in frequency. Future work is dedicated to building and testing a prototype of the design.

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1. Introduction

The 200 m flying start World Human Powered Vehicle speed record for single rider vehicles currently stands at 133.78 km/h and is was set by the Human Power Team Delft & Amsterdam (HPT) which consists of students of the Delft University of Technology and the Free University Amsterdam. The record was set with the third iteration design by the team in September of 2013 with their Velox 3 recumbent fully faired bicycle (see Figure 1). The new record was only a slight improvement over the previous record of 133.28km/h set by Sam Whittingham in de Varna Tempest 4 in 2009 at the same event, the World Human Powered Speed Challenge, in Battle Mountain, Nevada.

Figure 1.Velox3, recumbent fully faired bicycle, which holds the current World Human Powered Vehicle speed record for single rider vehicles at 133.78 km/h.

The HPT team develops their own recumbent fully faired bicycle each year. The first two bicycles that the HPT team developed, the Velox1 and Velox2 are similar to the Varna Tempest. Each being front wheel steered and front wheel driven recumbent bicycles, whilst the Velox3 is a front wheel steered, rear wheel driven recumbent bicycle (Human Power Team (2013)).

The development of a world record setting human powered vehicle is an interesting design problem with many trade-offs having to be made. However the most important aspect in designing such a high-speed bicycle is it's aerodynamic shape, usually described by the drag coefficient multiplied by the frontal area (C_dA). The power the rider produces to propel the bicycle forward at such high speeds mostly goes into overcoming the aerodynamic drag (Kyle and Weaver (2004)) Thus the more streamlined the shape of the fairing, or the smaller the frontal area, the higher the speed that can be attained.

With a Prone bike (prone position is a body position in which one lies flat with the chest down) a much smaller frontal area can be achieved than with a recumbent. However, the prone position is found to be more uncomfortable when breathing heavily, resulting in a lower power output by the rider, and thus the recumbent position is usually opted for. Whilst some designs have been made where the rider faces rearwards (Russo (2011)), most opt to keep the rider facing forward to reduce the mental load. In the recumbent position, with the rider facing forward, the rider's feet are located at the front end of the bicycle, thus requiring a long chain to drive the back wheel (as in the Velox3) with subsequent losses, or the front wheel is driven, causing unwanted steering due to the application of a moment on the steering assembly by the driven chain (as in the Velox1, Velox2 and Varna Tempest) resulting in an extra mental load for the rider who hast to counteract this steering torque by applying a counter torque to the handlebars.

One of the main aerodynamic disturbance features that currently all bicycles have is a relatively large gap in the bodywork around the front wheel. This gap is required to ensure that the wheel can be steered. The size of the gap depends on the required turning radius, where a larger radius allows for a smaller gap. The shell of the Velox is designed using CFD with aim of having a laminar airflow as far as possible along the body (Epema et al. (2012)). The gap induces turbulent airflow which is detrimental to the aerodynamic design.