Experimental Study of Steer-by-Wire Ratios and Response Curves in a Simulated High Speed Vehicle

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Abstract

In this poster, we outline a research study of the steering system for a potential land speed record vehicle.

We built a cockpit enclosure to simulate the interior space and employed a game engine to create a suitable virtual simulation and appropriate physical behaviour of the vehicle to give a realistic experience that has a suitable level of difficulty to represent the challenge of such a task. With this setup, we conducted experiments on different linear and non-linear steering response curves to find the most suitable steering configuration.

The results suggest that linear steering curves with a high steering ratio are better suited than non-linear curves, regardless of their gradient.

Keywords: Yoke, Steering, High Cognitive Load

1 Introduction

The task for the research team was to create an environment to undertake research on the cockpit design of a Land Speed Record vehicle, this being inspired by the public launch of the New Zealand "Jetblack" land speed record project, and our growing awareness of numerous land speed record projects sprouting up around the globe.

Creating this environment elevates the sensitivity of the quality of the user interaction design significantly, and will allow us to trial and evaluate many designs and gather rich data. The aim of our research in collecting this data is targeted at developing theory rather than just evaluating a set of designs or undertaking a requirements gathering activity. We do intend to develop the simulation to be as close to the physical reality as possible, as the land speed record context provides something concrete for participants driving in the simulator to imagine, and a target context for participants to relate their experiences. Making this context explicit then provides a fixed reference point to combine the variety of experiences of the participants that have ranged from games enthusiasts, pilots, drag race drivers, and engineers, to general office staff and students.

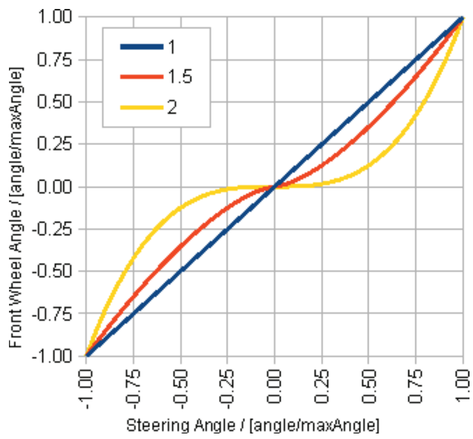

Figure 1: Linear and nonlinear response curves for the steering wheel

2 Steering Design

The steering of a landspeed record vehicle is very different from a standard automobile. Instead of a standard steering wheel, a yoke is used for controlling the vehicle. The rotation range of the yoke is limited to about 90 to at most 180 degrees, since the pilot constantly has to keep both hands on it. A larger motion range would result in crossing arms or uncomfortable rotation angles of arm and hand joints. In addition, the maximum range of the steering angle of the front wheels of the vehicle is very limited as well. The vehicle is designed primarily to drive a straight course without any bends. In our simulation, we found that during most runs, the front wheels were rarely rotated more than ±1 degree.

While there is a significant body of research into vehicle control via steering wheels, yokes, and joysticks, e.g., (McDowell et al. 2007, Hill et al. 2007) in the context of military vehicles, we were not able to find any research output in the context of high-speed land vehicles such as Jetblack.

For the experiments, we implemented a steering module with two parameters: an adjustable yoke/front wheel transfer ratio, and an adjustable response curve. The steering module expects the yoke input as a value between -1 and 1 and translates it to an intermediate value in the same range by applying a simple power function with an adjustable exponent. An exponent of 1 results in a linear curve while higher exponents (e.g., 1.5 or 2) result in the nonlinear curves shown in Figure 1.

The intermediate value is then multiplied by a factor that represents the steering ratio (e.g., 1:30 or 1:60), the ratio between the yoke input angle and the

Figure 2: Components of our simulator: Screen (top left), cockpit with yoke (centre) and computer running the vehicle simulation (bottom right).

front wheel output angle. As an example, for a yoke with a range of 90 degrees of rotation (±45 degrees), a 1:60 ratio would result in the front wheels being adjusted by 1.5 degrees (±0.75 degrees) for the full 90 degree movement.

3 Methodology

We implemented a vehicle simulator with a cockpit created from plywood, a Logitech G27 force feedback wheel and pedals, a large size projection screen, and a virtual simulation environment created with the Unity3D engine (see Figure 2). For the experiments, simulation-driven force feedback on the steering wheel was disabled, leaving only a medium spring force that would return the wheel to the centre position. We also removed the original steering wheel and replaced it by a yoke as discussed in Section 2.

The results presented in this poster were collected from three participants. To avoid the influence of the initial learning curve and distortion of the data by treating the simulation more like a game, we chose participants who were either familiar with the simulator and the serious nature of the experiment, or participants who had a background in driving real high-speed vehicles, e.g., New Zealand Drag Bike racers.

In total, we collected data of 60 runs with a mixture of the following steering configurations:

Configuration	Power	Ratio
1*	1 (linear)	1:20
2	1 (linear)	1:30
3	1 (linear)	1:45
4	1 (linear)	1:60
5	1.5 (quadratic)	1:45
6	2 (quadratic)	1:45
7*	3 (cubic)	1:45

The configurations were randomised and changed after every run. Configurations with an asterisk were only tested once or twice to test if the participants would notice such extreme values.

Data was logged for every timestep of the physical simulation which ran at 200 times per second. As a measure for the stability of a run, we evaluated the average of the lateral velocity of the vehicle during the acceleration phase at speeds above 500km/h. Above this speed, the randomised, simulated turbulences and side wind had a major effect on the stability of the vehicle, and therefore required most steering influence from the participants.

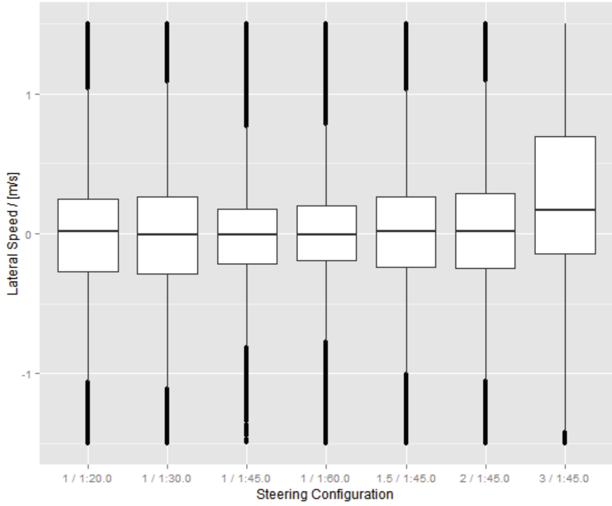

Figure 3: Analysis of the lateral speed of the vehicle for different steering configurations. (Dots at the top and bottom of the boxplots are outliers)

4 Results

The results are shown in Figure 3. We found that the linear response curves with a high steering ratio like 1:45 or 1:60 lead to the least amount of lateral velocity of the vehicle at speeds above 500km/h. The worst results were achieved using the quadratic or cubic response curve, even leading to crashes due to complete control loss of the vehicle.

Configuration	50% Inner Quartile Range
1	0.537 m/s
2	0.572 m/s
3	0.396 m/s
4	0.394 m/s
5	0.522 m/s
6	0.588 m/s
7	1.5611 m/s

An additional factor for the rejection of quadratic or higher exponents in the response curve is the fact that only for those configurations, the vehicle got out of control on some occasions while all runs with a linear curve were successful.

We are currently collecting more data with more participants to solidify the statistical significance of the data.

References

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