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Aerodynamic study of Human Powered Vehicles

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Abstract

The key areas with interest of Human Powered Vehicles (HPVs) are the significance of aerodynamic design and ways to improve overall aerodynamics. Wind tunnel testing was undertaken at the RMIT wind tunnel with a selection of both faired and unfaired vehicles. Within these tests and vehicles different components were also analysed and tested. The wind tunnel testing was used to identify key characteristics of these HPVs, and, by identifying the different results obtained it was possible to understand more about the aerodynamics of HPV. Drag force values were obtained during wind tunnel testing, these drag values were compiled and compared. A key result was the importance of fairings, where travel could require significantly less effort as the faired vehicle tested provided only a quarter of the aerodynamic hindrance of any of the unfaired vehicles. Another significant finding was the effect of vehicle add-ons which showed how some apparently small components could have a relatively large negative impact on drag.

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1. Introduction

With the current issues associated with fossil fuels and carbon emissions the need for alternate energy methods is greater than ever. The National Pollutant Inventory (2009-2010) suggests that transport is responsible for 13.5% of Australia’s total greenhouse gas emissions. There is a large focus in the issues and improvement of life is focusing on transportation, with this in mind current research is focussed on finding alternate fuel methods to power such vehicles. This study focuses on a great alternative for transportation that does not harm the environment and also provides the user with health benefits. The

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Human Powered Vehicle (HPV) is a pedal powered mode of transportation; therefore, its success is measured by the effective transfer of pedal power to forward motion. Mechanical power losses will not be considered in this study. Evidence suggests that despite low speeds, aerodynamic drag has a significant effect on average speed and rider fatigue (Zimmer and Alam [1], Hucho [2], Van Valkenburg [3], Becker and Dedini [4]). The aerodynamics of the vehicle are sometimes more important than the mechanical aspects of the vehicle. This hindrance causes a loss of effectiveness of power transfer to motion. The current study was aimed at understanding the aerodynamics, and in turn helping to achieve better efficiency of these vehicles and increasing the appeal of the HPV. There are many differing designs and industrial assumptions; with the aid of wind tunnel testing it was possible to isolate key designs and characteristics that make these vehicles successful. The tests were initially based on the vehicles to be presented in the Royal Automobile Club of Victoria (RACV) energy breakthrough challenge. The event involves close to 100 participants from various primary and secondary schools across Australia [5]. To validate findings the event was attended and the vehicles were analysed.

2. Methodology

The tests were held at the RMIT Industrial wind tunnel. The wind tunnel measures 3 m wide, 2 m high and 9 m long and can safely operate at wind speeds up to 140 km/h. All values and calculations can be derived from the experimental results obtained through a six component force sensor. Considering the HPV has three wheels, there is need for a support that will distribute weight from each of the wheels to a central point, used for calculating effective forces. A T-stand was designed so that a flat bar ran across the front two wheels and a U-channel ran through the centre of the vehicle all the way to support the rear wheel. The experimental set up in RMIT Wind Tunnel is shown in Fig 1.

![Fig. 1. Test set up in the test section of the wind tunnel](image)

This design provided minimal frontal surface area, therefore affecting results as little as possible. However, small the variance is, the test was run with the stand only to determine a zero point. The HPVs were securely laid on the T-stand that was inserted directly through the tunnel floor into a force sensor. The force sensor was used to measure drag, lift, side force, roll, pitch and yaw moments. Tests were run at increments of 10 km/h from 10 km/h up to 130 km/h. To correct any discrepancy between wind speed at the HPV and the wind tunnel wall-mounted Pitot tube, initially a Pitot tube was positioned at the HPV. Once the calibration error was known, the wind tunnel measurement system was used.

2.1 Test Vehicles

Seven HPVs were supplied by manufacturer Greenspeed for testing. The vehicles consisted of six bare trikes and one fully faired vehicle. Three vehicles including a faired one are shown in Fig 2.
The bare trikes came in various formations shapes and sizes, and these variations allowed for isolation of factors effecting aerodynamics and their respective efficiencies. The faired vehicle used was an industry leading vehicle that was the result of many years of design by Greenspeed. The faired vehicle, called the Glyde, also had various body additions and these components are used to alter the wind flow over the body of the vehicle, improving aerodynamics. These additions included a) canopy surrounding the drivers body so that the drivers head is the only part exposed to wind flow, b) visor used at the front of the canopy, this visor was used as a wind deflector to aid wind flow to separate before the drivers exposed head, and c) wheel covers, simply carbon fibre curved circles applied on the outer surface of the wheels, to reduce form drag of the wheels.

3. Results and Discussion

3.1 Seat Positioning

The first tests were focused on seating angle. The vehicle selected, the Magnum, had both height and rake adjustment for the seat and three different seat angles were determined. The reason for this was to isolate both the effects of seating angle and seating height. The three tests were: (i) a low seat reclined back, (ii) a high seat reclined back, and (iii) a high seat reclined forward.

The findings provided both expected and unexpected results as shown in Fig 3. It can be observed that high-forward position has the highest drag, due to the increased frontal area and the more abrupt figure. Based on aerodynamic principle, it can be understood that wind flow must be smooth in order to reduce drag therefore with the low reclined position a smooth airflow can be observed that provides less drag. The interesting point however, is the difference in the seating heights. One would expect a higher drag from the higher position due to an increase in frontal area. This can be explained by analysis of the seating positions. When the seating position is reclined and high, although uncomfortable the driver maintains a straighter line from his head to feet than that of the lower seating position. This also demonstrated at lower velocities the higher position allows for less turbulence at the base of the seat.
however as the velocity increases lamination occurs nullifying this effect, indicating the difference between low speed and high speed design. The result identifies the importance of not only decreasing frontal area but also of creating a smoother flow path.

3.2 Add-ons

A vehicle was selected with the possibility for a variety of add-ons that affect the driver’s ability, functionality and safety. There were four different add-ons analysed and compared: (i) a rear rack, (ii) rear bags, (iii) mirror, and (iv) a flag, as shown in Fig 4. Figure 5 identifies the drag differences between the different add-ons. Figure 5 demonstrates a) that as velocities increase the significance of these little components reduce; b) that although the rack and bags are large figures their significance is relatively small as they are mounted behind the driver’s seat and only protrude slightly to either side of the driver, c) the small flag mounted on the top of the seat provided the largest hindrance to aerodynamic forces.

3.3 Faired vehicle variations

3.3.1 Canopy

The faired vehicle with and without canopy is shown in Fig 6. The first improvement was a cowling type canopy, different however to the one noted previously. This one acts as a cover for the driver’s body around the manhole. This minimises the opening as it is applied after the driver enters the vehicle. The canopy used was faulty from the factory due to overheating, the result was a warped structure and this difficulty was overcome by use of masking tape to seal the edges. However, the use canopy reduced the aerodynamic drag at all speeds tested (Fig 7).

3.3.2 Visor

The visor was a simple thin Perspex piece that was aimed at deflecting the wind from the driver’s head.
(see Fig 8). The visor is believed to be designed as a comfort feature more than an aerodynamic feature however the visor provides both aerodynamic and comfort benefits. One of the bluff bodies left uncovered from the fairing is the driver’s head which is a rough figure. By diverting air away from the head and the headrest it should be possible to minimise drag further. The visor was attached by masking tape. This has the effect of blending the visor-body edge. Figure 9 illustrates the benefit of using a visor. The effect of visor is less at low speeds (below 50 km/h) significantly higher at medium velocities (50 to 70 km/h), and is lower at high speeds (above 70 km/h). The three stages can be identified by the use of a moving average trend line and these are believed to be due to the flow separation of the vehicle, with separated airflow from the base of the visor.

![Fig. 8. Vehicle with canopy and visor](image1)

![Fig. 9. Visor comparison with moving average](image2)

### 3.3.3 Wheel covers

The final modification was the wheel covers. Wheel covers are designed to reduce the form drag (pressure drag) caused by wheel spokes and cavities as shown in Fig 10. Figure 11 identifies the significance of wheel covers where compared to other modifications, the wheel covers provide a larger benefit. Figure 11 indicates that a vehicle could travel 90 km/h with the wheel covers within the same drag experienced at 80 km/h without wheel covers.

![Fig. 10. Wheel covers](image3)

![Fig. 11. Comparison of drag with the wheel covers](image4)

### 3.4 Vehicles comparison

The aerodynamic drags at 3 speeds (30, 40 and 50 km/h) for seven vehicles are shown in Fig 12. For the Magnum vehicle, the drag for seat orientation is also shown in the figure. It is clearly demonstrated that the vehicle with fairing (Glyde) possesses the lowest aerodynamic drag at all speeds tested. The Magnum vehicle possesses the highest drag among all vehicles as it has the largest frontal area.
4 Analysis of Race Event

The annual 2011 RACV (Royal Automotive Club of Victoria) Energy Breakthrough HPV racing event was held in Marryborough, a country town approximately 150 km from Melbourne. Observations indicated that seating angle was a big factor as the leading vehicles had a far reclined position allowing for a reduction frontal area, even less than that of the vehicles tested above. Another important factor was the addition of external components, with the less successful race participants’ vehicles having different components outside of the vehicle body, while the leaders of the race either removed components or enclosed them. For example, the race winner had a specific cowling for the required rear vision mirrors and the second place finisher has the mirrors within the faired body. When looking at data found in the wind tunnel testing, it can be seen that factors to decrease drag were used by all the top ten overall race finishers. Similarly the factors that negatively affected drag were all adopted by all the bottom 30 finishers. One school entrant with the Glyde finished 8th of 22 in its class, which is quite a good result, however the vehicle had external mirrors not wheel covers no visor and, something we did not analyse, it missed a cowling covering the rear wheel. Had all these differences been rectified the team may have been able to do much better. Another interesting characteristic observed was the vehicles with smooth flow. Although some vehicles had a small frontal area some had somewhat rough figures, where wind flow would not have a smooth path, and these vehicles were without major race success. Although their shapes were smooth, the few vehicles that had drivers heads external to the main body did not have any visor or wind deflection.

5. Conclusion

The magnitude of aerodynamic drag significantly varies with the test vehicles’ physical profiles. The HPV manufacturers do not necessarily take into account the importance of aerodynamics in unfaired vehicle design. The fairings and canopy used in this study showed a significant reduction in aerodynamic drag compared to unfaired vehicles and open faired vehicles. The seating position in a HPV plays an important role. The reclining position further backward allows a further reduction of frontal area thus lowering drag. Additionally, the reclining position further backward may provide better physical advantages for endurance as indicated by observation at a race event. As expected, component add-ons and their positions generally increase drag more at low speeds than at high speeds.

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