The effect of crosswinds on cyclists

Fintelman, D. M.; Sterling, M.; Hemida, H.; Li, F. X.

DOI:
10.1016/j.proeng.2014.06.122

Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 72 (2014) 720 – 725

Procedia Engineering

www.elsevier.com/locate/procedia

The 2014 conference of the International Sports Engineering Association

The effect of crosswinds on cyclists: an experimental study

D.M. Fintelman[a], M. Sterling[b], H. Hemida[b], F.-X. Li[a]*

[a] *School of Sport, Exercise and Rehabilitation Sciences, University of Birmingham, Edgbaston, Birmingham, B15 2TT, United Kingdom*
[b] *School of Civil Engineering, University of Birmingham, Edgbaston, Birmingham, B15 2TT, United Kingdom*

Abstract

The aims of this research were to firstly investigate the effect of crosswinds on the aerodynamic behaviour of cyclists and secondly, to determine which parameters (cyclist position and bike type) influenced the aerodynamic forces on cyclists the most. The aerodynamic response of two different full-scale bikes with and without a mannequin has been recorded for a variety of crosswind angles ranging from $0^o – 90^o$ (in 15^o increments). The results showed that the wind induced force is a function of the crosswind angle. The actual aerodynamic loads arising from such winds can be up to about 2.5 times the aerodynamic drag. It has also been observed that the torso angle has little effect on the lateral force coefficient. In contrast, the bike type significantly affects the aerodynamic forces: at large yaw angles, a road bike is responsible for approximately 60 % of the total lateral force coefficient. This study is the first step in the process of determining the effect of crosswind from a full range of angles of attack on cyclists, and will help to improve the safety of cyclists and equipment, and to define guidelines for cycling lanes.

Selection and peer-review under responsibility of the Centre for Sports Engineering Research, Sheffield Hallam University

Keywords: Aerodynamics; bicycling; crosswind; wind tunnel; moments

Nomenclature

CdA aerodynamic drag force coefficient (m^2)
CsA aerodynamic side force coefficient (m^2)
ClA aerodynamic lift force coefficient (m^2)
CpA aerodynamic pitch moment coefficient (m^2)

* Corresponding author. Tel.: +44-121-414-4114; fax: +44-121-414-4121.
E-mail address: f.x.li@bham.ac.uk

Selection and peer-review under responsibility of the Centre for Sports Engineering Research, Sheffield Hallam University
doi:10.1016/j.proeng.2014.06.122

CrA aerodynamic roll moment coefficient (m^2)
CyA aerodynamic yaw moment coefficient (m^2)

1. Introduction

During cycling, crosswinds can have a significant impact on the performance, stability and safety of a cyclist. Even though only about 5% of all cycling accidents are caused by crosswind, it is reported that the majority leads to severe or fatal accidents (Ryan, 2012; Schepers and Wolt, 2012). Nevertheless, there is evidence to suggest that about two-thirds of the total number casualties (slight injuries, serious injuries and fatalities) in road accidents are unreported (Department of Transport, 2012). Despite the occurrence of fatal accidents due to crosswinds, there are limited studies investigating the aerodynamic responses of cyclists under such conditions. Current literature mainly focuses on windless environmental conditions (Chabroux et al., 2012; Gibertini et al., 2008; Lukes et al., 2005). Whilst these experiments provide important information about the aerodynamic performance of cyclists, it is a poor approximation for conditions which regularly occur. Recent studies showed that equipment has a significant effect on the aerodynamic load of a cyclist (Barry et al., 2012). However, only a limited range of yaw angles (i.e., the angle the wind makes with the cyclists direction of travel, i.e., β in Fig. 1) have been analysed, i.e. up to 30°. In contrast, in the rail and automotive industry a wide range of yaw angles (0-90°) are often considered, since it is appreciated that the worse case conditions can occur for yaw angles greater than 30°. In conclusion, although it has been suggested that crosswinds have a significant effect on the aerodynamic forces of cyclists, influencing their performance and stability, this is the first comprehensive study to provide vital information relating to cyclist stability.

2. Method

2.1. Wind tunnel

A subsonic open return wind tunnel with a cross-sectional area of 2x2 m was used for the work outlined below. The wind speed was measured with a 3-axis ultrasonic anemometer at a sampling frequency of 10 Hz (Gill Windmaster, Gill Instruments Ltd, Lymington, UK). The turbulence intensity (i.e., the standard deviation / mean wind speed) at the edge of the wind tunnel was 0.67 %. The aerodynamic forces and moments were recorded with a multi-component piezoelectric force plate (Kistler type 9281B, Kistler Instruments, Winterthur, Switzerland) which was integrated in a custom built turntable. The wheels of the bike were connected to the force platform by means of a frame with uprights (Fig. 1). The force plate was capable of measuring the aerodynamic forces and moments around the three axes at a sampling frequency of 1 kHz. The aerodynamic forces were repeatable to within ± 0.05 N. The coordinate system was placed in the bike reference frame and hence independent of the relative flow direction.

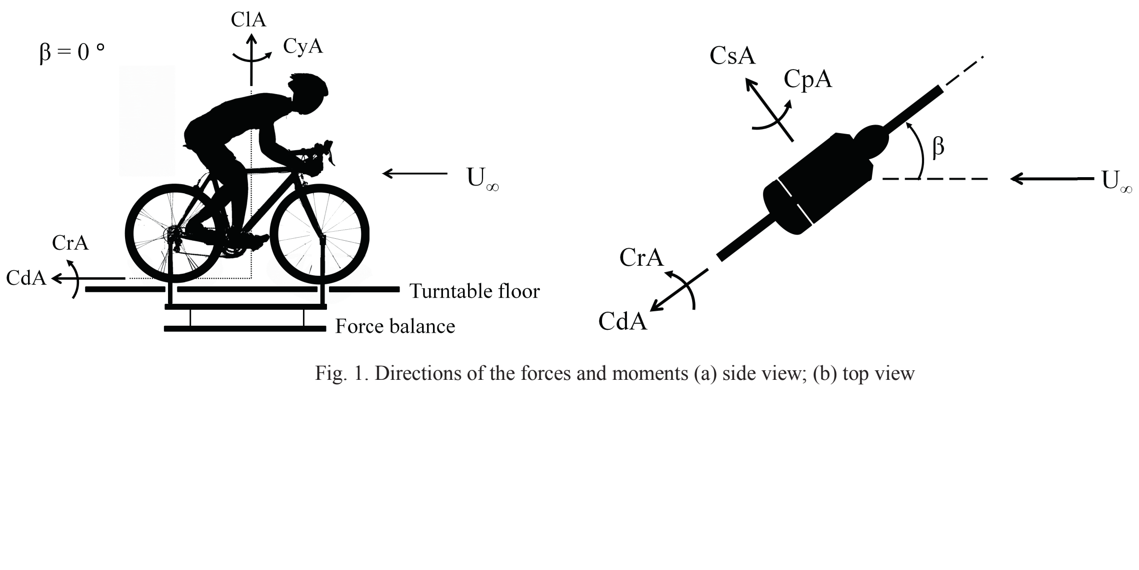

Fig. 1. Directions of the forces and moments (a) side view; (b) top view

2.2. Aerodynamic testing

The sign convention adopted is illustrated in Fig. 1. Yaw angles, β, of 0^o, 15^o, 30^o, 45^o, 60^o, 75^o and 90^o were examined. Every yaw angle trial was repeated at least 3 times, determined from a confidence interval analysis with a significance level of 95 %. The total measured period was 80 seconds. The first 20 seconds allowed sufficient time for the flow in the wind tunnel to become stable. Only the final 60 seconds of the total measured data, in which the wind is steady, has been analysed.

Firstly, the effect of yaw angle on the aerodynamic force coefficient at a constant wind speed has been determined. In all the experiments, a mannequin (PolyStar Man, Creatif Leven Displays Ltd, Gloucester, UK) was placed in a dropped position on a road bike (CIOCC Dragster, CIOCC ISB SRL, Bergamo, Italy) in a constant main flow velocity (U_∞) of 9.91 m/s, unless otherwise stated (Fig. 2a). Secondly, the individual contributions of the bike and uprights were evaluated for a range of yaw angles. Thirdly, the effect of torso angle on the aerodynamic responses at different yaw angles was measured. Two different torso angle positions were considered, i.e. 16^o and 24^o torso angle relative to the ground. In both configurations the hands were kept in the dropped position (Fig. 2a-b). Finally, the aerodynamic behaviour of two isolated bikes was determined (Fig. 2c-d). A road bike was compared with a TT bike (Felt B12, Felt racing LLC, Irvine, USA) with a rear disk wheel (DT Swiss RRC, DT Swiss AG, Biel, Switzerland).

Fig. 2. (a) 16^o torso angle position; (b) 24^o torso angle position; (c) road bike; (d) time trial bike.

2.3. Data analysis

All data analysis was undertaken using Matlab (Matlab R2007B, The MathWorks Inc., Natick, USA). The recorded data was compensated for drift, calibration corrections, and two environmental variables, i.e. temperature and humidity. Finally, the data has been corrected for blockage area with the method of Mercker and Wiedemann (1996).

3. Results and Discussion

3.1. Force coefficients

In Fig. 3 the force coefficient data relating to the mannequin and bike are shown. The data had an average standard deviation of around 0.02 m^2. It should be mentioned that error bars of the standard deviation are included in Fig. 3-6. The side force coefficients, CsA, of the mannequin and bike increase with increasing yaw angles, while the opposite behaviour is noted in the drag force coefficients (CdA). The maximum side forces coefficients were more than twice the maximal drag forces coefficients. The measured lift force coefficients were small compared to both the side and drag force coefficient data. The maximal CdA was measured at β = 15^o. It should be noted that the largest gradients in CsA can be found for yaw angles up to 45^o. The individual contributions of the uprights, bike and mannequin on the total aerodynamic force coefficients are also shown in Fig. 3. For a pure head wind (β = 0^o) approximately 8 % of the drag is caused by the uprights and approximately 27 % of the drag coefficient is responsible for the combination of the road bike and the uprights. It is noticeable that the lift force is predominantly related to the mannequin for the majority of the yaw angles. At a 90^o crosswind, approximately 61 % of the total side force coefficient is caused by the bike and uprights, while the uprights accounts for only about 5 % of the total side force coefficient. It should be noted that the use of uprights does have a small contribution to the measured aerodynamic forces for all yaw angles.

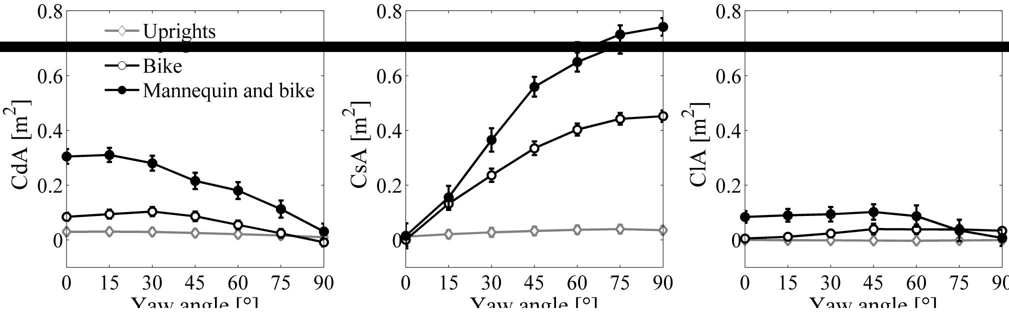

Fig. 3. Distribution of the aerodynamic coefficients between the uprights, bike and mannequin, (a) drag force coefficient, CdA; (b) side force coefficient CsA; (c) lift force coefficient ClA.

The effects of two torso angle positions (16^o and 24^o) on the aerodynamic responses are shown in Fig. 4. The drag force coefficient significantly decreased with about 0.05 m^2 at a yaw angle of $\beta = 15^o$ in a small torso angle position (16^o) compared to a more upright position (24^o). A drag force reduction up to 15 % can be experienced by lowering the torso angle. This reduction diminished with increasing torso angle. No significant difference in side and lift force coefficient was recorded between the two torso angle positions.

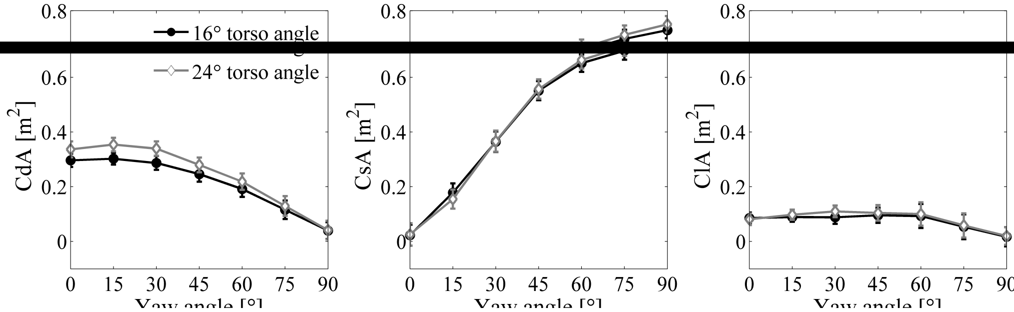

Fig. 4. Aerodynamic responses of the mannequin in a 16^o and 24^o torso angle position relative to the ground.

In Fig. 5 the aerodynamic force coefficients acting on a TT bike and road bike are shown. Although the drag force coefficients of a TT bike are up to 50 % smaller (0.05 m^2) compared to a road bike, the side force coefficients were up to 34 % (0.15 m^2) higher for increasing yaw angles. The lift force coefficient on the road bike was positive with increasing angles, while negative for the TT bike. Furthermore, the maximal drag force coefficient of the TT bike is approximately 6 times smaller than the maximal side force coefficient.

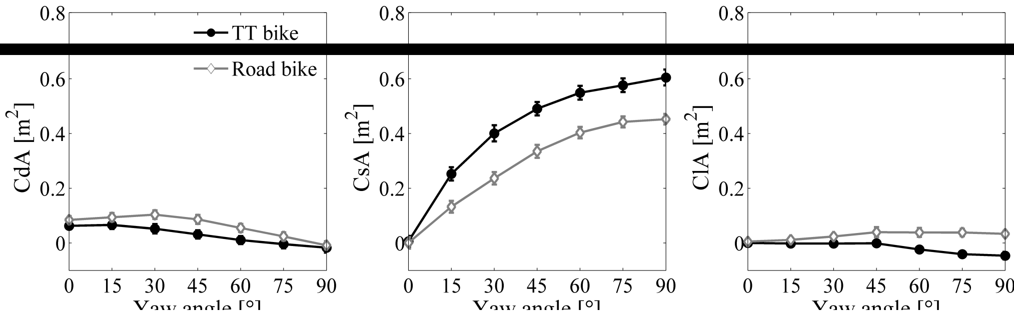

Fig. 5. Aerodynamic behaviour of a TT bike and road bike at different angles of attack.

3.2. Moment coefficients

In Fig. 6 the aerodynamic moment coefficients are shown. The roll moment, CrA, increased significantly between 0^o and 60^o, indicating the importance of considering the full range of yaw angles in stability analysis. The pitch moment, CpA, decreased (in absolute terms) as the yaw angle increased, while the maximum yaw moment is observed to occur at approximately 30^o.

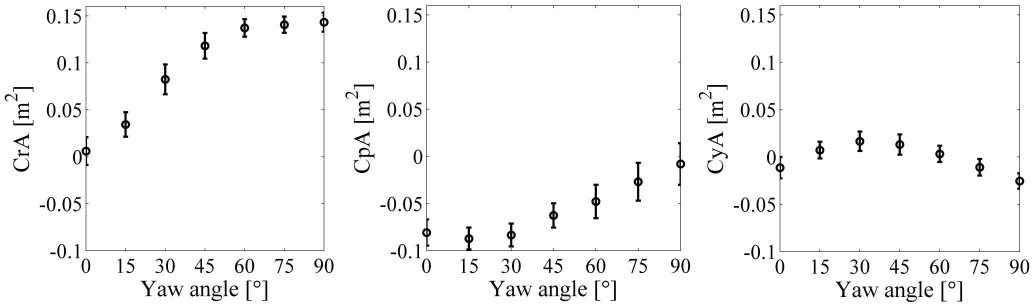

Fig. 6. Aerodynamic moment coefficients for different yaw angles (a) roll moment coefficient CrA; (b) pitch moment coefficient CpA; (c) yaw moment coefficient CyA.

The rolling moment coefficient CrA is mainly determined by the vertical moment arm of the side force. Hence, a close correlation ($p<.001$) can be seen between the CrA and side force coefficients CsA (see Fig. 7). The corresponding phase plots show also a strong, almost linear correlation. The behaviour observed in the CpA data is mainly determined by the vertical arm of the drag force, while the contribution to the yawing moment CyA is equally shared between the horizontal moment arm of the side forces and drag forces.

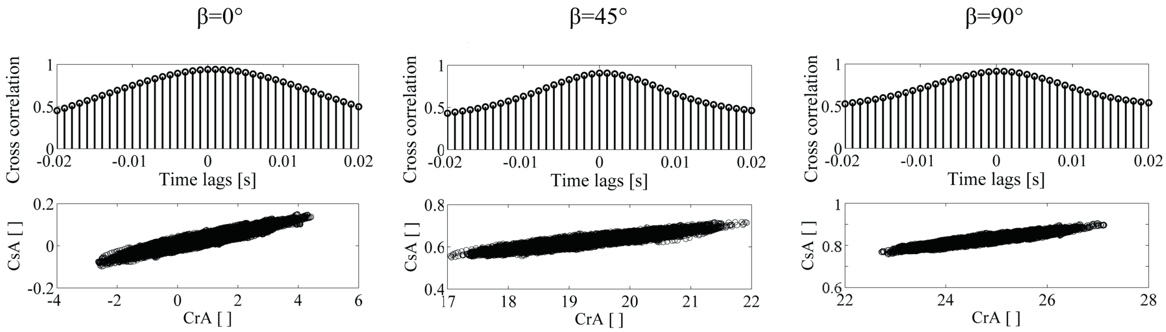

Fig. 7. Cross correlation and phase plot of side force coefficient CsA versus roll moment coefficient CrA at different yaw angles (a) $\beta = 0°$ (R^2=0.88, $p<.001$); (b) $\beta = 45°$ (R^2=0.82, $p<.001$); (c) $\beta = 90°$ (R^2=0.83, $p<.001$).

4. Discussion

In this work, wind tunnel experiments were conducted to investigate the effect of crosswind on the aerodynamic load of cyclist. It has been shown that the aerodynamic force coefficients are strongly influenced by the yaw angle, in keeping with similar trends found in road and train vehicles studies. In general a peak lift force coefficient around β =45^o is obtained, which can be justified by the transition of a slender body to a bluff body behaviour (Bocciolone et al., 2008). However, it should be mentioned that the standard deviation of the lift forces are about 20 % of the measured data and for β <45^o the change in lift force is within the standard deviation of the data. It can be expected that the flow pattern around a cyclist differs for different angles of attack. At high yaw angles it is postulated that the aerodynamic force coefficients are influenced by the wake flow structures created by the cyclist. At these angles the wake structures on the lee side of the bike are likely to contribute strongly to both the lift and side forces. The maximum drag at low yaw angles (β =15^o) can be explained by the non-aerodynamic shape and increased frontal area of the bike and mannequin.

This study also extended our knowledge on the parameters (cyclist position and bike type) that affect mostly the aerodynamic behaviour of a cyclist for an extensive range of crosswind angles. Results showed that the cyclist themselves accounts for the highest percentage of aerodynamic drag force coefficient (up to 74 % at $\beta = 0^o$), in line with Barry et al (2012). Whereas previous studies investigated yaw angles up to 30 ^{o}, the current study explored a wider range of yaw angles and showed that the bike has a progressively larger contribution to the total aerodynamic side forces as the yaw angle increases. When the yaw angle is 90°, up to half of the total aerodynamic side force coefficient contributes to the bike. Therefore, the side forces and corresponding roll moments can be reduced by decreasing the side surface area of the bike. However, it is likely that this may lead to an increase in the total aerodynamic drag force. For example, a rear disk wheel can decrease the aerodynamic drag by approximately 7 % at $\beta = 0^o$, but can also increase the aerodynamic side forces of the cyclist with about 20 % at $\beta = 90^o$ and hence may affect the safety of the cyclist. Therefore, cyclists should consider the potential risk of instability or falling by selecting their bike and wheel type depending on the wind conditions.

5. Conclusion

The effect of crosswind over a large range of yaw angles on the aerodynamic responses has been investigated. The results showed that crosswind has a significant effect on the aerodynamic forces and moments. In particular, the bike type does have a significant influence on the aerodynamic lateral load of a cyclist. A TT bike with rear disk wheel can increase the lateral load of the cyclist up to 20% compared to a road bike.

This study demonstrates that large crosswind yaw angles have a significant effect on the stability of the cyclist and shows the importance of the bike selection and design on the aerodynamic lateral load on a cyclist. These findings will help to improve the safety of cyclists and equipment, and to define guidelines for cycling lanes. Future analysis should attempt to gain insight of the flow pattern around a cyclist and the effect of a gust of wind on the aerodynamics and stability of cyclists by means of Computational Fluid Dynamic Simulations.

References

Barry, N., Burton, D., Crouch, T., Sheridan, J., Luescher, R., 2012. Effect of crosswinds and wheel selection on the aerodynamic behavior of a cyclist. Procedia Engineering 34, pp. 20-25.

Bocciolone, M., Cheli, F., Corradi, R., Muggiasca, S., Tomasini, G., 2008. Crosswind action on rail vehicles: Wind tunnel experimental analyses. Journal of Wind Engineering and Industrial Aerodynamics 96, pp. 584-610.

Chabroux, V., Barelle, C., Favier, D., 2012. Aerodynamics of Cyclist Posture, Bicycle and Helmet Characteristics in Time Trial Stage. J Appl Biomech 28, pp. 317-323.

Gibertini, G., Campanardi, G., Grassi, D., Macchi, C., 2008. Aerodynamics of biker position, BBAA VI International Colloquium on: Bluff Bodies Aerodynamics & Applications, pp. 20–24.

Lukes, R., Chin, S., Haake, S., 2005. The understanding and development of cycling aerodynamics. Sports Engineering 8, pp. 59-74.

Mercker, E., Wiedemann, J., 1996. On the Correction of Interference Effects in Open Jet Wind Tunnels. SAE International, doi:10.4271/960671.

Ryan, B., 2012. Andy Schleck crashes in Critérium du Dauphiné time trial, Cycling news.

Schepers, P., Wolt, K., 2012. Single-bicycle crash types and characteristics. Cycling Research International 2, pp. 119-135.

Great Britain. Department of Transport, 2012. Reported Road Casualties in Great Britain: Main Results 2011, Statistical Release.