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NUMERICAL ANALYSIS OF THE DRAG COEFFICIENT OF A MOTORCYCLE HELMET

Abstract

The paper discusses a numerical investigation, using a CFD tool, ANSYS FLUENT, of drag acting on a motorcycle helmet. The simulations were performed on a model of a helmet downloaded from a free CAD model library. A solid model enabled us to generate a mesh, to define boundary conditions and to specify a model of turbulence. Accordingly, the values of forces acting on individual sections of the helmet were obtained and the coefficients of aerodynamic drag were calculated. The test results can be used to optimize the shape of the existing motorcycle helmet construction and to study the impact of generated drag forces on reaction forces affecting a motorcyclist's body.

1. INTRODUCTION

Motorcycle helmets, unlike cycling helmets, are of a complex design, have a protective face visor and are elongated enough to protect middle and lower head sections. Rice et al. (2016) state that the motorcycle helmet protects both the head and neck from injuries. Weight of such helmets is not as important

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as that of cycling helmets. The key aspect is the best possible head protection in a crash. The helmet should protect not only against open wounds, but also significant acceleration – deceleration (*United Nations Economic Commission for Europe*, 2016). Helmet mechanical strength is regulated by the United Nations Economic Commission for Europe 22.05 Helmet Standard and the Federal Motor Vehicle Safety Standard No. 218 by the U.S. Department of Transportation. The relationship between a motorcycle helmet design and safety is comprehensively investigated by Fernandes and Alves de Sousa (2013).

Helmet strength and a helmet ability to fast absorb energy should be also accompanied by efficient helmet aerodynamics. The resulting drag should be as small as possible to have as reduced an impact on the human body, especially the neck, trunk and arms as possible. Drag can be reduced by changing the helmet shape, i.e. reducing the friction coefficient, or by reducing the front surface. The front surface cannot by freely modified due to design requirements as the helmet needs to be thick enough to efficiently protect the entire head surface. Reshaping the helmet, therefore, is the main method to reduce the emerging drag force while driving. Today's manufacturing technologies allow for even very sophisticated shapes. Typical production methods include material lamination or thermo-plastic processing. A rounded shape improves not only helmet aerodynamics, but also helmet strength (no indentations causing a locally accumulated tension).

One of the methods to aerodynamically examine the motorcycle helmet is a CFD-based numerical study which enables the distribution of velocity and pressure on the surface and around the research object. It is also possible to observe streamlines and to calculate drag coefficients. This method can be supported by experimental tests of the model, conducted in real conditions or in a wind tunnel.

Many research papers on the aerodynamic analysis of crash helmets focus on numerical testing of helmets for cyclists. Such structures have a streamlined shape (similar to the shape of a drop), cover only the upper part of the head, may have ventilation holes, and at the same time have a small mass. In addition, usually the air velocity flowing around the cycling helmet is less than the air speed flowing around the motorcycle helmet. Brownlie et al. (2010) present the results of aerodynamic drag tests for 12 different cycling helmets for different yaw angles. In the publication wrote by Beaumont, Taiara, Polidori, Trenchard and Grappe (2018) numerical tests of aerodynamic drag of various cycling helmets were made depending on the different position of the head in relation to the incoming air. With the strongly profiled shape of the helmet, the angle of the head position significantly influences the drag. This is due to the increase in the area of the frontal surface. This is confirmed by the research conducted by Alam, Chowdhurya, Zhi Weia, Mustarya and Zimmerb (2014), where the influence of ventilating holes placed on the surface of the helmet on the generated aerodynamic drag was examined.

In addition to the research of aerodynamics of crash helmets, there are publications investigating the aerodynamics of the entire driver's silhouette. Brownlie et al. (2009) show the impact of the cyclist's apparel on the generated aerodynamic drag. It is common knowledge that moving a two-wheeled vehicle behind the previous vehicle results in a reduction in the drag force. In the study by Blocken and Toparlar (2015), the influence of a car moving behind a cyclist on the drag force acting on it was examined. Numerical studies were compared with wind tunnel tests. It was found that a significant reduction in resistance (by several percent) occurs when the distance of the vehicle from the rider does not exceed 5 m. A similar research was carried out by Blocken, Toparlar and Andrianne (2016) where the car was replaced by a motorcycle. Blocken, Defraeye, Koninckx, Carmelit and Hespel (2013) also studied the aerodynamic drag generated by three cyclists moving behind them.

The aim of this work was to examine the drag coefficient of a motorcycle helmet, taking into account the interference drag generated by the human body. For this purpose, numerical calculations for different air flow velocities were made based on the prepared solid model of the test object. As a result of the calculations, the values of forces on individual elements of the test object were obtained. The surface of the elements necessary to calculate the resistance coefficient was measured using the CAD software.

2. RESEARCH OBJECT

The research object is a model of a motorcycle helmet downloaded from a free GrabCAD model library [grabcad.com] connected with a CATIA V5 model of a human trunk with arms and a neck. Connecting the research object with a part of the human body was to show real conditions of the airflow while riding a motorcycle. Such calculations will certainly include the geometry of the motorcycle. This approach, however, depends much on a type of motorcycle so the geometric model selected for our first calculations is shown in Figure 1.

The position of the model in regard to the global coordinate system is shown in Figure 2. The following axis designations have been adopted: x – longitudinal axis (in line with the direction of the velocity vector), y – transverse axis, z – vertical axis. The dimensions of the model are: 328 x 560 x 555 mm (length x width x height). The research object was placed in a computational domain with dimensions 5328 x 4560 x 3555 mm (length x width x height). A velocity inlet and pressure outlet were defined on it. The test object was defined as a wall element. The direction of the velocity vector of the incoming air is the same as the direction of the x-axis.

For such a model, a mesh of 1,522,977 Tet4- and Wed6-type cells, see Figure 1, was created. The model is segmented into basic elements such as a visor, a helmet body and a human body with a neck. Turbulence model k–ω SST, combining the advantages of the *k–ε* and *k–ω* models, is applied in our simulation. This type of turbulence model perfectly maps the wall turbulent flow and still maps free flow turbulence. SST (Shear Stress Transport) means that the values of major tensions in the flow are limited. The calculation parameters selected in the solver are pressure-based and steady state.

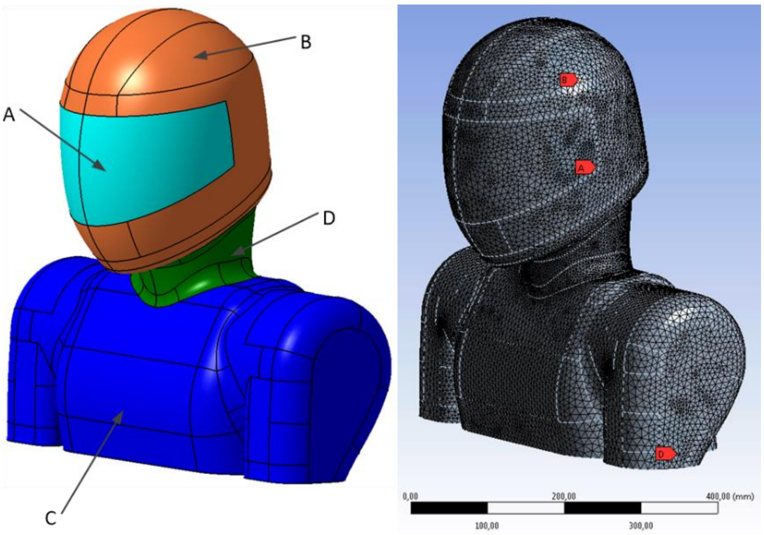

Fig. 1. The solid model of the test object divided into wall elements (visor A, helmet B, body C, neck D) and the view of the generated calculation grid model

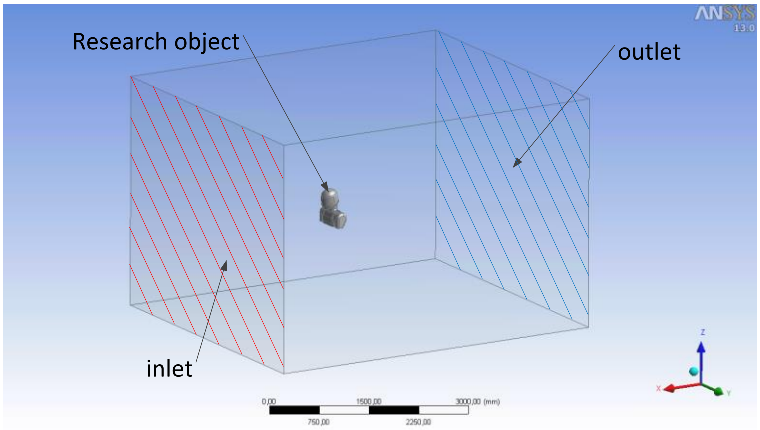

Fig. 2. The research object in the research area with the boundary conditions – isometric projection

The working agent is air defined as an ideal gas of 15°C and a viscosity of 1.7894·10-5 kg/(ms). The phenomenon of turbulence has been characterized by two parameters: intensity and length scale. It has been assumed that the intensity of turbulence is 5%, while the length scale at the inlet and outlet of the measurement area is 0.81 m. The length scale refers to the size of the turbulence in relation to the size of the duct.

For the model prepared in this way, a series of simulations were carried out for different velocities of the flowing air. Measuring points accepted for the calculation are: v = 5.56 m/s, 13.89 m/s, 27.78 m/s, 41.67 m/s.

3. RESULTS

As a result of the numerical analysis, pressure and velocity distributions were obtained on the tested motorcycle helmet for four calculation cases. Figures 3–5 present the examples of pressure contours on the surface of the research object and in the plane of symmetry for the velocity of the flowing air equal to 13.89 m/s, 27.78 m/s, 41.67 m/s, respectively. Figures 6–7 show the contours of velocity in the plane of symmetry for the velocity of flowing air equal to 5.56 m/s, 13.89 m/s, 27.78 m/s, 41.67 m/s, respectively. The drag forces generated on the individual helmet sections for varied airflow speeds are given in Table 1.

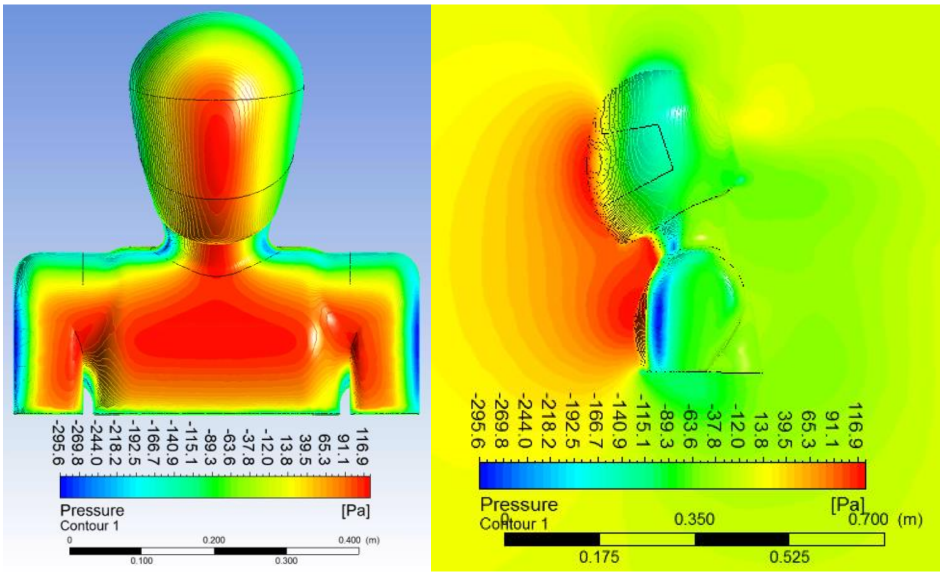

Fig. 3. The pressure contours on the surface of the research object and in the plane of symmetry for the velocity of the flowing air *v* equal to *v* = 13.89 m/s

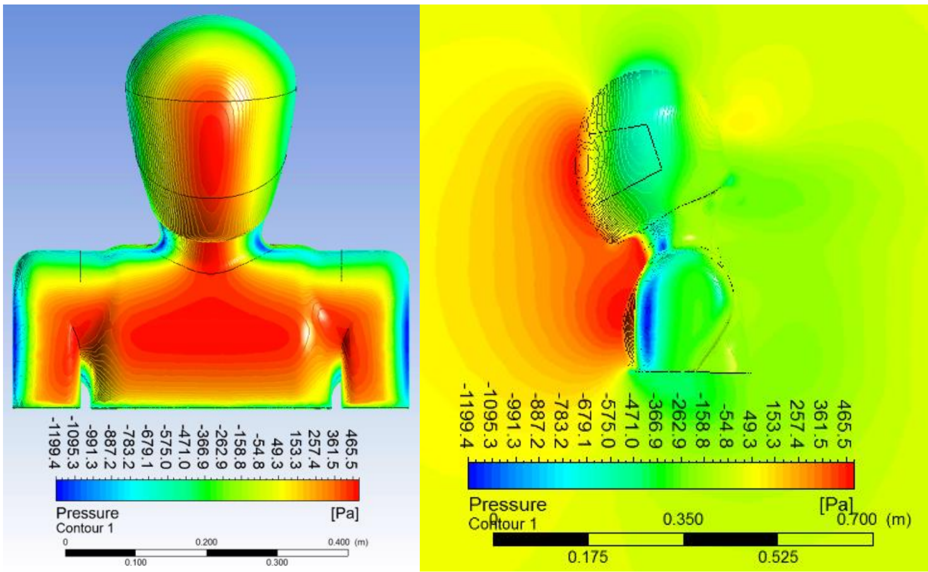

Fig. 4. The pressure contours on the surface of the research object and in the plane of symmetry for the velocity of the flowing air *v* equal to *v* = 27.78 m/s

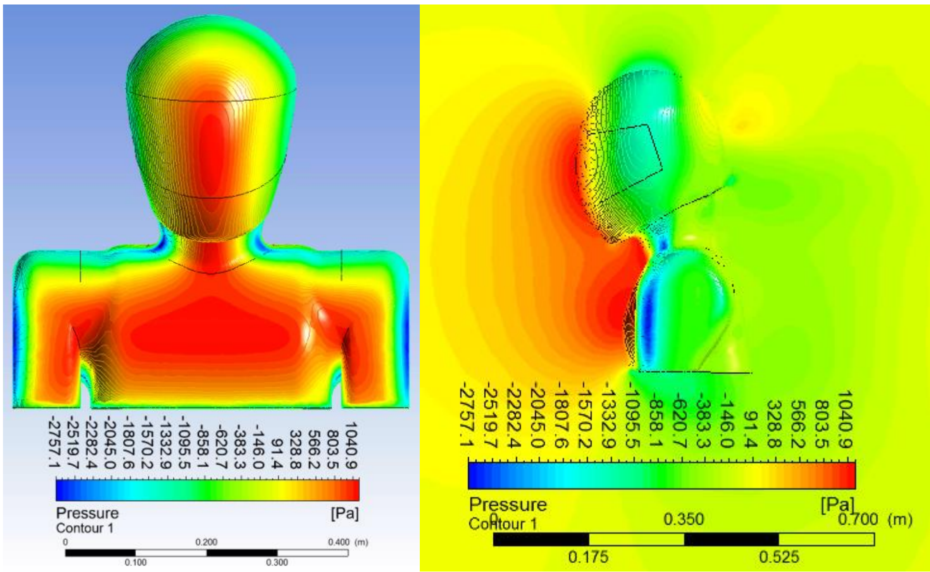

Fig. 5. The pressure contours on the surface of the research object and in the plane of symmetry for the velocity of the flowing air *v* equal to *v* = 41.67 m/s

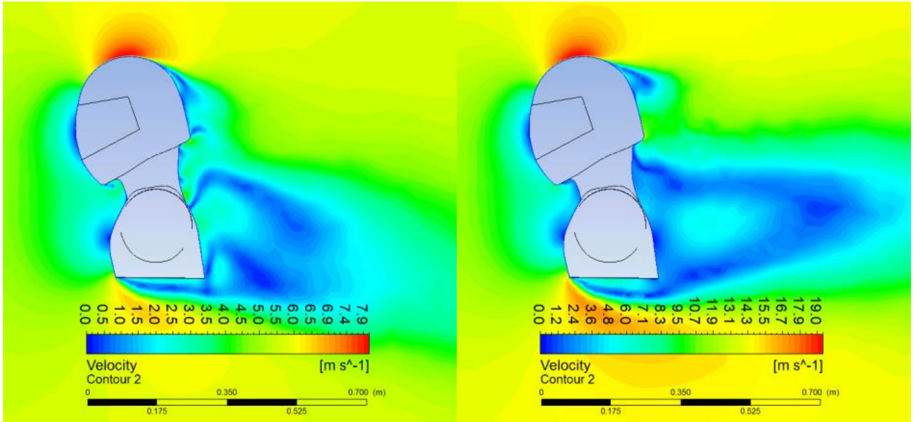

Fig. 7. The velocity contours in the plane of symmetry for velocity of flowing air *v* equal to 5.56 m/s (left) and for 13.89 m/s (right)

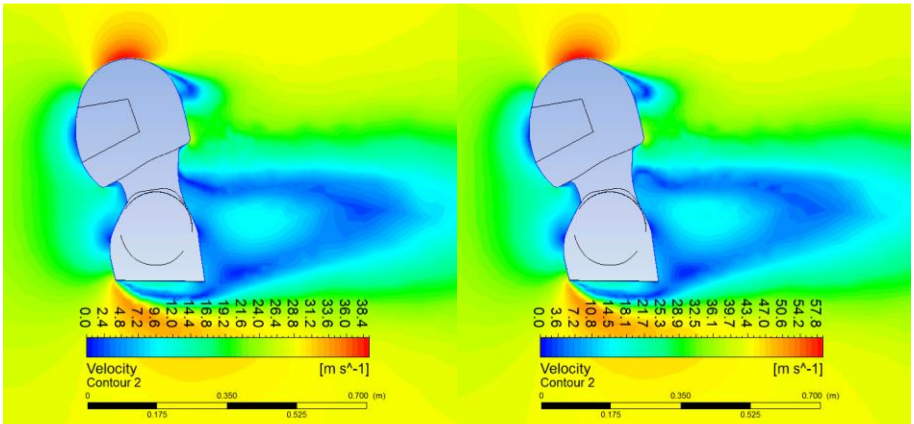

Fig. 8. The velocity contours in the plane of symmetry for velocity of flowing air *v* equal to 27.78 m/s (left) and for 41.67 m/s (right)

Tab. 1. Generated drag force for the research object

Case	Velocity *v* (m/s)	Drag force (N)				
		Visor	Helmet	Neck	Body	Total
#	0	0	0	0	0	0
1	5.56	0.155	0.547	0.209	1.980	2.890
2	13.89	1.180	2.833	0.962	10.726	15.701
3	27.78	4.582	10.558	3.501	42.431	61.0718
4	41.67	10.069	23.047	7.658	96.813	137.583

The front surfaces of the individual sections of the research object are measured in the CATIA V5, see Table 2. These values enabled us to calculate the value of the drag coefficient generated on the each of the sections of the research object in line with model (1), and the results are given in Table 3.

Tab. 2. Surface area of the individual elements of the research object

Element	Surface area S (m^2)
Visor	0.028187
Helmet	0.033473
Neck	0.006631
Body	0.127460

$$C_{xi} = \frac{P_{xi}}{0{,}5 \cdot \rho \cdot v^2 \cdot S_i} \tag{1}$$

where: P_{xi} – aerodynamic drag force on the *i* element,
ρ – air density,
v – velocity of flowing air,
S_i – frontal area of the *i* element.

Tab. 3. Calculated drag force coefficient for the research object

Case	Velocity v (m/s)	Drag force coefficient C_x (–)			
		Visor	Helmet	Neck	Body
#	0	–	–	–	–
1	5.56	0.291	0.864	1.667	0.821
2	13.89	0.354	0.716	1.227	0.712
3	27.78	0.344	0.667	1.117	0.704
4	41.67	0.336	0.647	1.086	0.714

The column charts in Figure 9 depict the correlation between the drag generated on the individual helmet sections and the airflow speeds.

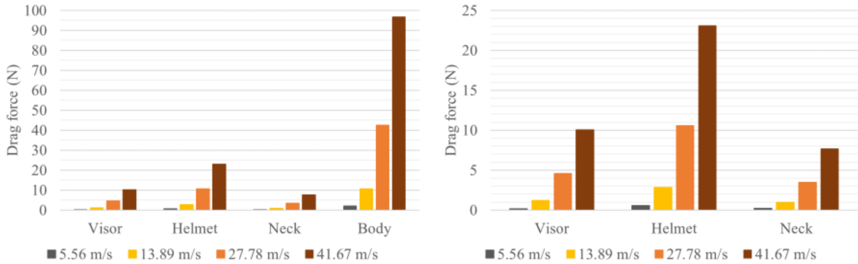

Fig. 9. Drag force on all of the simulated helmet sections (left) and the drag force for the selected helmet sections versus the flowing air velocity (right)

The total drag force as a function of airflow speed was plotted from the calculations. The plotted points enabled a 2nd order polynomial trendline, see Figure 10, according to equation (2):

$$P_x = 0.0061v^2 + 0.0033v + 0.189 \tag{2}$$

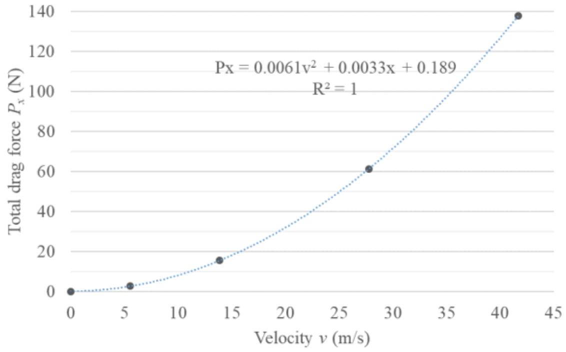

Fig. 10. The total drag force as a function of the velocity of the flowing air

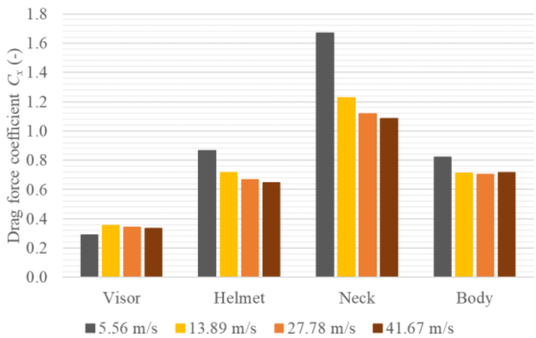

Fig. 11. Drag force coefficients for the individual elements of the research object depending on the velocity of flowing air

4. DISCUSSION AND CONCLUSIONS

Our calculations enabled us to claim that an accumulated pressure is the central sections of the visor and the trunk. The maximum value of overpressure for the airflow speed equal to 5.56 m/s is 21.39 Pa and increases with increasing speeds to reach 125.45 Pa, 500.2 Pa, 1120.05 Pa, respectively. The vacuum occurs on the rounded helmet edges, the neck edges and the shoulders as a result of the air speeding up at a rounded shape, which results in a decreased pressure (in line with Bernoulli's principle). The absolute value of the vacuum generated at the helmet edges is about 28 Pa at 5.56 m/s and is increasing with increasing speed to reach 146 Pa, 589, 1338 Pa, respectively. The highest vacuum occurs on the shoulder. The total drag force varies according to the square of the airflow speed. Its value for the airflow velocity of 41.67 m/s was equal to 137.6 N. This force is transferred to the arms and legs of the motorcyclist in the form of reaction forces. The largest value of the drag force component is generated on the motorcyclist's body. It can be reduced by tilting his body forward and using a motorcycle handlebars cover. Other elements (visor, helmet, neck) produce several times less drag. The drag force generated on the helmet's casing is twice as large as the force on the visor.

Based on the research performed, it was found that in the future it is possible to carry out extended aerodynamic analysis taking into account the additional geometry of the cover on the motorcycle handlebars for the different angle of the motorcyclist's body. This would allow us to examine the loads occurring on individual parts of the motorcyclist's body resulting from the impact of aerodynamic forces.

REFERENCES

Alam, F., Chowdhurya, H., Zhi Weia, H., Mustarya, I., & Zimmerb, G. (2014). Aerodynamics of ribbed bicycle racing helmets. *Procedia Engineering, 72,* 691–696. doi:10.1016/j.proeng.2014.06.117

Beaumont, F., Taiara, R., Polidori, G., Trenchard, H., & Grappe, F. (2018). Aerodynamic study of time-trial helmets in cycling racing using CFD analysis. *Journal of Biomechanics, 67,* 1–8. doi:10.1016/j.jbiomech.2017.10.042

Blocken, B., & Toparlar, Y. (2015). A following car influences cyclist drag: CFD simulations and wind tunnel measurements. *Journal of Wind Engineering and Industrial Aerodynamics, 145,* 178–186. doi:10.1016/j.jweia.2015.06.015

Blocken, B., Defraeye, T., Koninckx, E., Carmeliet, J., & Hespel, P. (2013). CFD simulations of the aerodynamic drag of two drafting cyclists. *Computers & Fluids, 71,* 435–445. doi:10.1016/j.compfluid.2012.11.012

Blocken, B., Toparlar, Y., & Andrianne, T. (2016). Aerodynamic benefit for a cyclist by a following motorcycle. *Journal of Wind Engineering and Industrial Aerodynamics, 155,* 1–10. doi:10.1016/j.jweia.2016.04.008

Brownlie, L., Kyle, C., Carbo, J., Demarest, N., & Harber, E. (2009). Streamlining the time trial apparel of cyclists: the Nike Swift Spin project. *Sports Technology, 2,* 53–60. doi:10.1002/jst.12

Brownlie, L., Ostafichuk, P., Tews, E., Muller, H., Briggs, E., & Franks, K. (2010). The wind-averaged aerodynamic drag of competitive time trial cycling helmets. *Procedia Engineering*, *2*, 2419–2424. doi:10.1016/j.proeng.2010.04.009

Fernandes, F. A., & Alves de Sousa, R. J. (2013). Motorcycle helmets – a state of the art review. *Accident Analysis & Prevention*, *56*, 1-21. doi:10.1016/j.aap.2013.03.011

Rice, T. M., Troszak, L., Ouellet, J. V., Erhardt, T., Smith, G. S., & Tsai, B.W. (2016). Motorcycle helmet use and the risk of head, neck, and fatal injury: Revisiting the Hurt Study. *Accident Analysis and Prevention*, *91*, 200–207. doi:10.1016/j.aap.2016.03.002

United Nations Economic Commission for Europe. (2016). *The United Nations Motorcycle Helmet Study*, *United Nations*, New York and Geneva. doi:10.18356/82cd1e4b-en