Effects of Crosswind on an Automobile Under Dynamic Conditions

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Abstract: This paper presents results of a series of experiments carried out on models of a car and a truck in a wind tunnel to observe the pressure coefficient variation when the truck was overtaken by the car. However, conventional wind tunnels are not equipped to measure the yaw moment and side force created due to pressure difference created as a result of the interaction of two vehicles and the cross wind. An additional attachment for the wind tunnel was designed and built to measure the yawing moment and the side force experienced by the car when the cross wind is applied. The attachment consists of a "top plate" which is independent from the wind tunnel frame and free to rotate. The car model is fixed to the "top plate" the top plate is connected to the base plate via a load measuring shaft which is connected to load cells that enable to measure the yaw moment. The pressure coefficient variation was measured by a series of pressure tapings provided by the circumference of the car. The two models were tested independently in the wind tunnel for their pressure coefficient variation. It was found that the pressure coefficient around the car varies substantially when it is overtaking the truck. It was also observed that when the cross wind is applied the yawing moment and the side force on the car increases with the air speed. The attachment was calibrated prior to the investigation and have been able to obtain consistent results. To relate the observations to real world conditions, further investigations are necessary.

Keywords: Pressure Coefficient, Aero-dynamic Behavior, Overtaking Vehicles

1 Introduction

In recent years the number of vehicles driven on roads has rapidly increased across the world. Due to this the vehicles overtaking one another is prevalent in motorways. Overtaking in a vehicle highly involves several skills and driving techniques in variable road conditions. These include a clear vision of the road ahead, and knowledge and understanding of other vehicles that might be affected – approaching vehicles from the front, trailing vehicles and the ones surrounding the vehicle to overtake. Moreover, it requires correct perception and reflexes required for quick responses during highway driving condition. Further it involves judgment of speed and distance along with the judicious use of various car accessories like the rear view and side mirrors, transmission, steering wheel, and the braking system. On the other hand as one vehicle passes another during an overtaking maneuver the flow fields around the two vehicles interact generating transient aerodynamic forces [1]. Further, the influence of cross wind on the maneuverability and stability of vehicles is a major concern when it comes to safety of highways. Hammand et al [2] have reported that the forces and moments acting on a passenger car during a crossing maneuver may change by up to 43% and may last only for a period of 0.01s. However, the authors have concluded the fact that the phenomenon is not fully understood and further investigations are needed.

Continuous development in the automobile industry has led to both faster and lighter vehicles. Lighter vehicles are necessary for vehicle's manufacturers to fulfill the requirements of both fuel economy and raw materials conservation [3]. In particular such lighter vehicles are susceptible to a severe drift when overtaking (or when overtaken by) a larger vehicle [4].

The variation of aerodynamic influence on vehicles was first shown by Bearman (1984) [5]. The same fact was also addressed by Sims-Williams (2001) [6], Duell and George (1993) [7] and Gilhome et al. (2001) [8]. The aerodynamic influence of a passing vehicle on the motion stability of other vehicles has been discussed by Yamamoto et al. (1997) [9]. They made statistical and dynamical comparisons for the influence of the aerodynamic force acting on a passenger vehicle which is overtaken by a bus. The result shows that the dynamic effect is small in the range where the relative speed is small. Moreover, they have concluded that the influence of the aerodynamic force generated by the passing bus on the motion of the passenger vehicle will appear greater in the yawing moment. The wind tunnel experiments were carried out by L. Tsuei and Ö. Savas. [10], to study the transient aerodynamic forces experienced by members of a four – car platoon during passing maneuvers with a single vehicle. The results of their study showed that every car in the platoon experienced significant changes of drag and side force coefficients when the passing model moved to the proximity of each car. But they have not mentioned anything about the pressure coefficient variation.

The previous studies have examined the aerodynamic impact on a passenger vehicle when overtaken by a heavy vehicle such as a truck or another light vehicle of the same type. But for the author's best knowledge this is the first occasion where the aerodynamic impact of a passenger vehicle is examined experimentally, when the passenger vehicle is overtaking a heavy vehicle. Furthermore, it is expected to measure the Drag force (N), Lift force (N), Side force (N), Pitching moment (Nm) and Yaw moment (Nm). A special retrofit was also developed to measure the said forces as the present experiment facility does not facilitate yaw moment measurement.

2 Experimental facility and methodology

2.1 Pressure Measurements

The experiments were conducted in an Open circuit type downdraft wind tunnel available at the Department of Mechanical engineering, The Open university of Sri Lanka. The test section of the wind tunnel is made out of clear acrylic and has dimensions 600 mm × 304 mm × 304 mm. The wind tunnel is computer controlled and there is a display unit which displays the instantaneous values of drag, lift and pitching moment. Fig.1 shows a photograph of the wind tunnel. There are 20 manometer tubes available and they are separately fixed outside the wind tunnel to measure the various readings of pressure tappings. Apart from these a Pitot tube attachment with the scale to measure the pressure distribution across the test section is also available. It could be travel horizontally as well as vertically to measure pressure at relevant locations.

Fig.1 The Wind Tunnel Used for Experiments

In this study, two vehicle models were tested namely car and truck which are shown in Fig. 2.

Ten pressure tappings points were fixed around the circumference of each model. The pressure was measured by a range of manometers. Fig.3 shows the way how tubes were connected in order to measure the pressure. The other ends of these tubes were connected to 20 separate manometers that are shown in Fig.3.

Fig.2 Test Models: The Car and the Tanker

Fig.3 Pressure Tapping Connection Tubes Fitted to the Car

The schematic diagram of the exact points where the pressure tappings are located in each model are given in Fig.4. The tapping points are indicated as C1, C2, etc.

Even though there are many tapping points marked in the Fig.3, pressure was measured only 7 tapping points depending on the availability of the manometer facility.

At the beginning of the experiments the two vehicle models were independently tested for pressure variation around them by varying the wind velocity. The pressure readings of each tapping were taken for five wind velocities from 5 m/s to 25 m/s with 5 m/s interval.

This is mainly to validate the wind tunnel measuring devices. After that the truck and the car were placed in different positions as shown in Fig. 5. The seven sub figures in the Fig. 5, show the seven different configurations of how the car and the truck were arranged during different experiments. At the beginning of the experiments the two vehicle models were

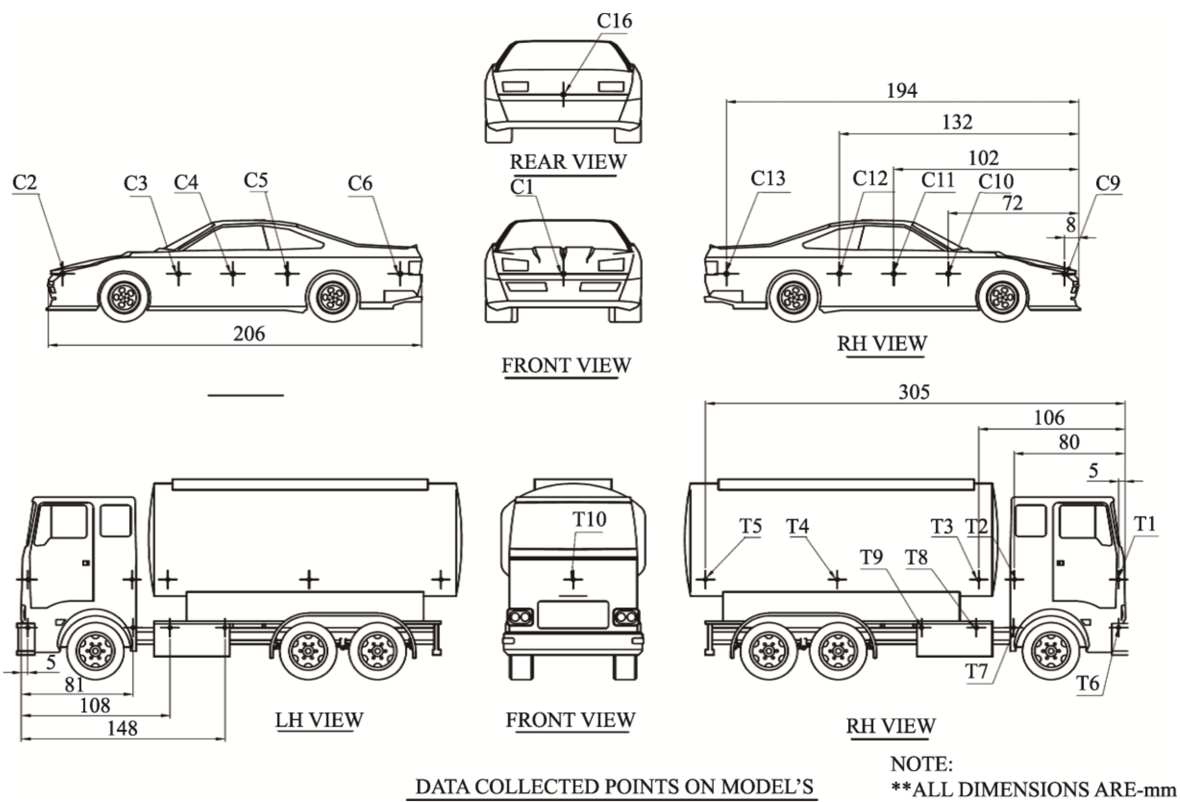

Fig.4 Schematic Diagram of Locations of Pressure Tappings

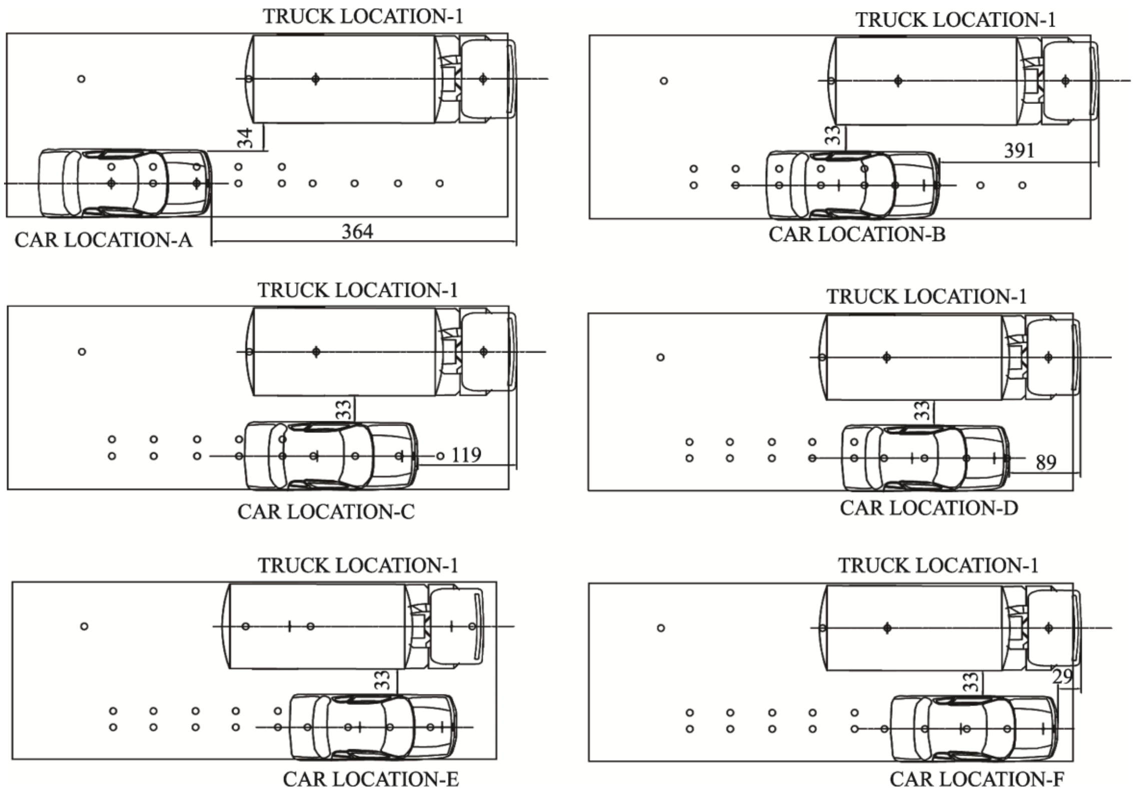

Fig.5 Schematic Diagram of Different Positions of Car and the Truck That Shows the Instances of Overtaking

independently tested for pressure variation around them by varying the wind velocity. The pressure readings of each tapping were taken for five wind velocities from 5 m/s to 25 m/s with 5 m/s interval.

2.2 Force Measurements

An attachment was developed to measure the Yaw moment (Nm) is shown in Fig. 6. The attachment was firmly connected to the bottom main support frame of the wind tunnel by means of the mounting plate. The base frame consists of necessary provision to mount the bottom guiding thrust bearing for the force transfer shaft and the platform to connect the two load cells that has been employed to measure the yaw moment.

The force transfer shaft is free to rotate about the top and bottom thrust bearings and the moment acting on the test model placed on the top frame was measured by the two load cells intended to measure the yaw moment. A pictorial view of the base plate attachment is shown in Fig.7.

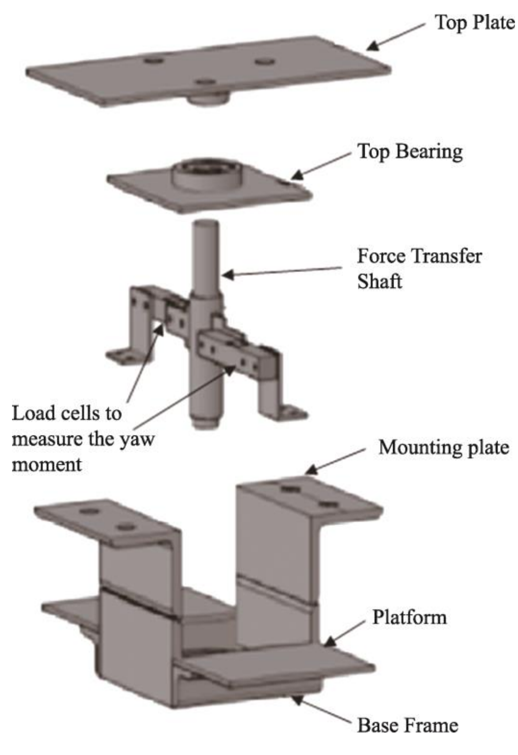

Fig.6 Exploded View of the Base Attachment

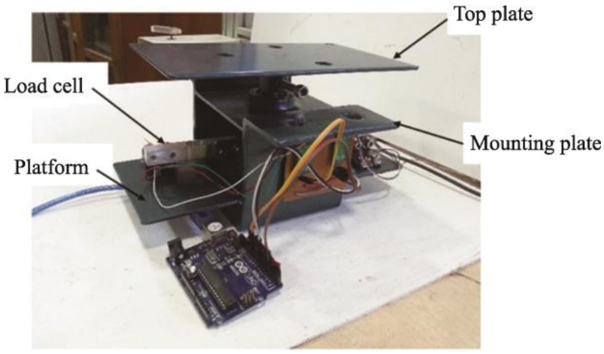

Fig.7 A Pictorial View of the Base Attachment

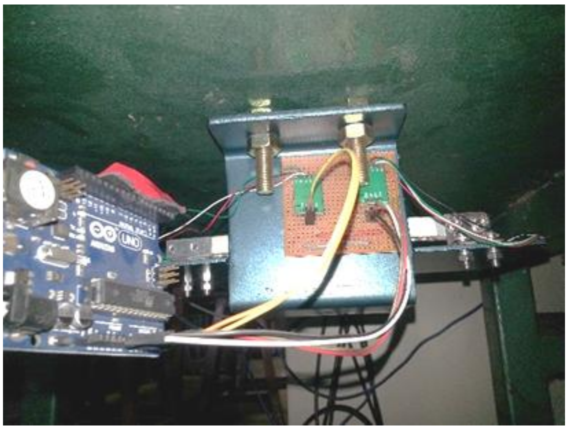

Fig.8 Connection of the Attachment to the Wind Tunnel

The base attachment was mounted to the wind tunnel from the bottom side and was not exposed to the active wind flowing area of the wind tunnel. The height between the mounting plate and the top plate was selected in such a manner that the top plate lie just above the bottom plate of the wind tunnel as shown in Fig.8.

On the top plate of the attachment, two more additional load cells were mounted to measure the lift force and pitch moment. The data acquisition was accomplished by means of an Arduino-Uno micro processor coupled with a laptop as shown in Fig. 9. The resistance variation of the loadcell was converted to a voltage by means of a Wheatstone bridge and further amplification by means of a signal amplifier.

This device comprised with two load cells. Therefore, the load cells were calibrated to get accurate readings about the yawing moments on the experiment model. The load cells readings, out from the Arduino board, depends according to the force applied to it and the relation between two readings known as Calibration factor of each load cell.

The car model was similarly tested for the cross wind effect by supplying cross wind with two different velocities. A special compressed air supply was attached from side of the wind tunnel to provide the cross wind effect as shown in Fig. 10. The cross wind was applied with two speed: 15 m/s and 25m/s.

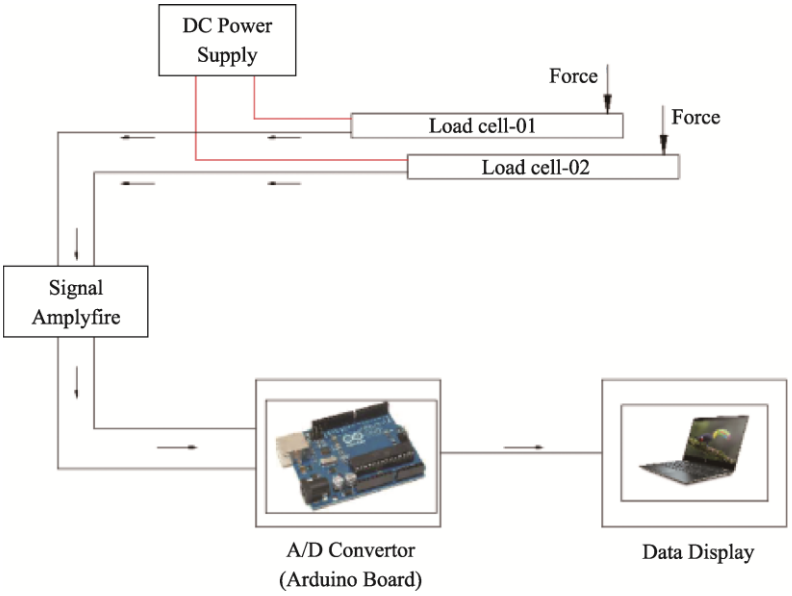

Fig.9 Data Acquisition

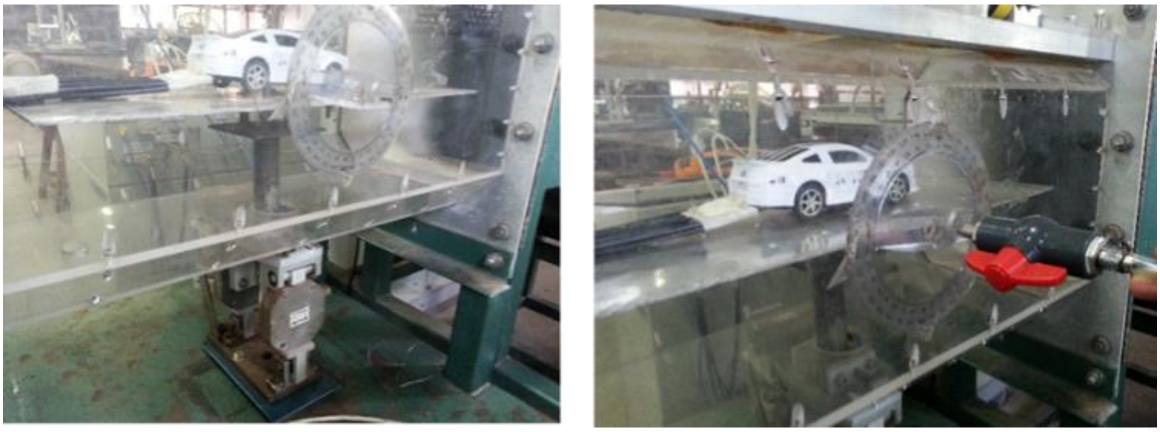

Fig.10 Arrangement of Supply of Cross Wind

3 Results

The pressure coefficient (Cp) was calculated for each measured pressure values for all trials. Fig. 11 shows the variation of Cp values, for five wind speeds for the car whereas Fig. 12 shows variation of the same for the truck. The variation of pressure coefficient of the car and the truck when tested independently, comply with the results of Nakashima (2013) [11], who performed a similar numerical study.

The variation of C_p corresponds to different positions of the car when overtaking was taken place, shown in Fig. 13. Each sub figure in Fig. 13 corresponds to each sub figure in Fig. 5, that shows the position of the car and the truck.

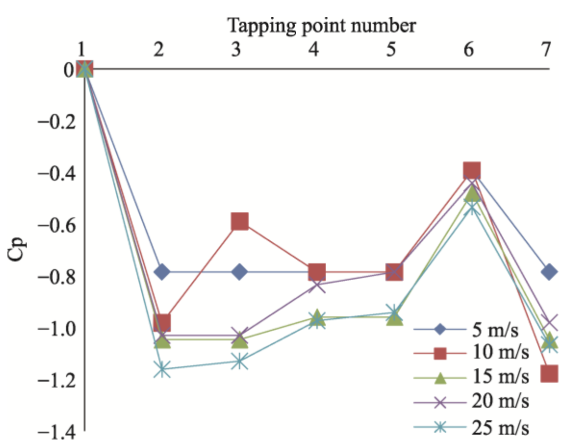

Fig.11 Variation of Cp for Different Wind Speeds of the Wind Tunnel for the Car

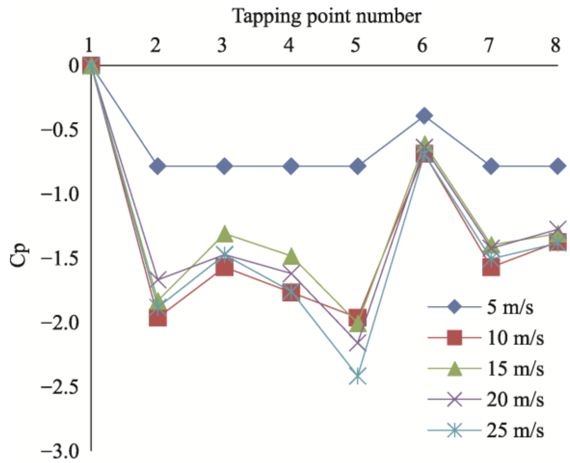

Fig.12 Variation of Cp for Different Wind Speeds of the Wind Tunnel for the Truck

It can be seen from Fig. 13 that when the car completed the overtaking the Cp value become negative for tapping points 4 – 8, which are at the far end of the car. This is same for all the wind speeds. Fig. 13 clearly shows variation of pressure coefficient and thus the aerodynamic effect on the car when overtaking a heavy vehicle.

The car was tested to observe the variation of yawing moment with the air speed. Fig. 14 shows the variation of average yawing moment for crosswind speed 15 m/s and 25 m/s. The yawing moment increases when the air speed increases for both the cross wind speeds apart from the two readings.

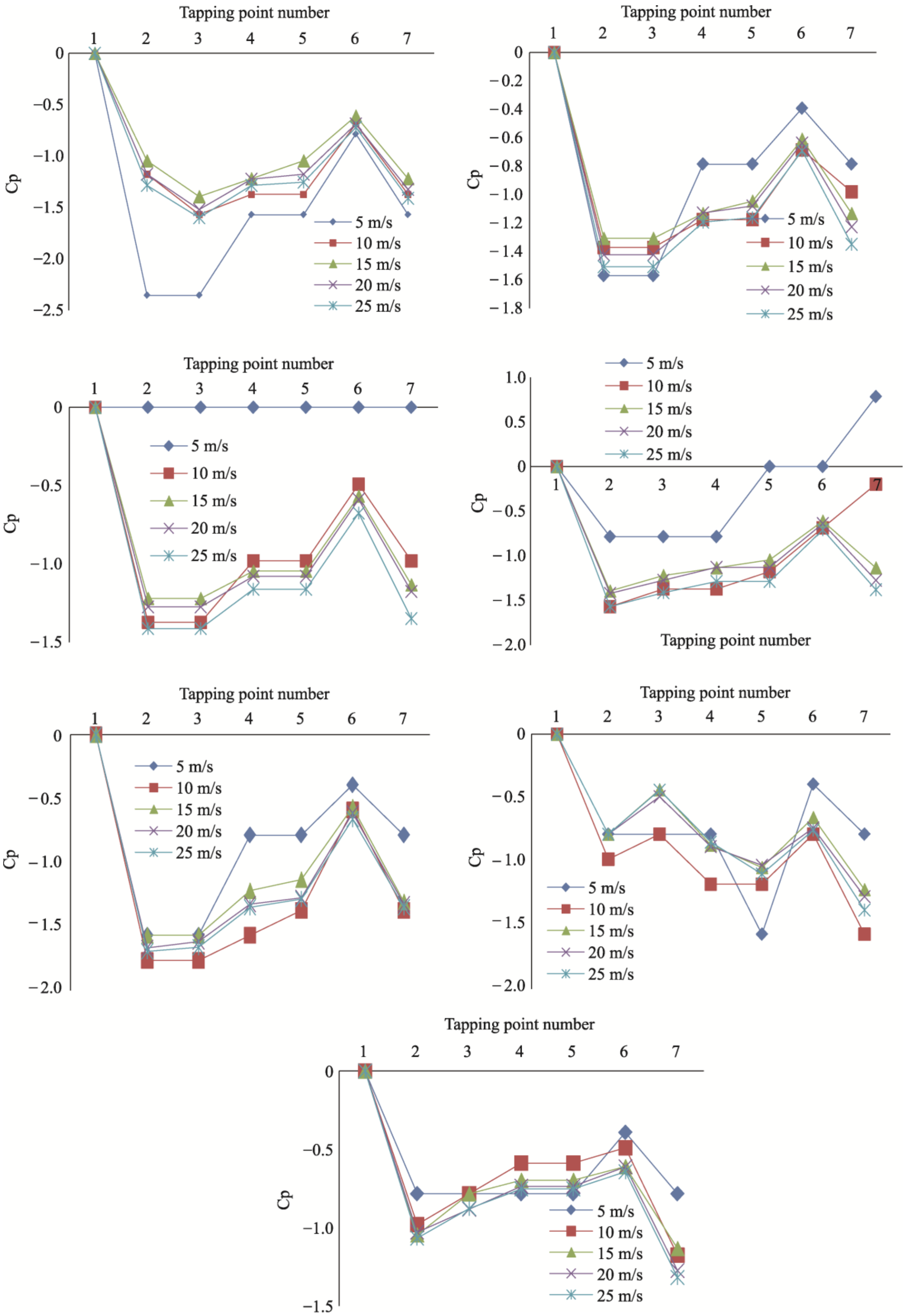

Fig.13 Variation of the Cp of the Car When Overtaking

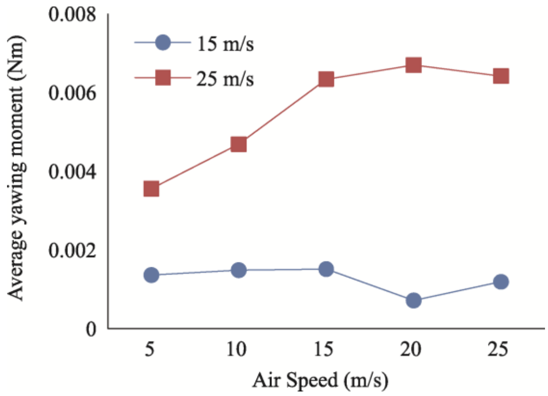

Fig.14 Variation of Average Yawing Moment with the Air Speed

4 Conclusions

A series of experiments were carried out to quantify the pressure coefficient variation around a body of a passenger vehicle when it is overtaking a heavy vehicle, A model of a car and a truck was used to carry out the experiments and it was observed that the pressure coefficient tends to increase its negative value when the speed of the air increases. It concludes that when the overtaking speed of the car increases a vacuum is created around the car. The yawing moment also increases when the cross wind is applied for different air speeds which in turn concludes that when the speed of the vehicle increases the cross wind effect increases the yawing moment.

References

[1] R. Corin, L. He, R. Dominy, A CFD investigation into the transient aero-dynamic forces on overtaking road vehicle models, Journal of Wind Engineering and Industrial Aerodynamics 96 (2008) 1390-1411.

[2] Hammad, A., Xing, T., Abdel-Rahim, A., Durgesh V., Crepeau JC,(2019) Effect of Crosswinds on the Aerodynamics of Two Passenger Cars Crossing Each Other. Int.J Automot. Technol. 20, 997–1008

[3] Telionis, D.P.. Fahrner, C.J. and Jones, G.S. An Experimental Study of Highway Aerodynamic Interferences. Journal of Wind Engineering and Industrial Aerodynamics 17, pp 267-293, 1984 and DOT Eng. Rep. No. HS-805025, 1980.

[4] Ahmed F. Abdel Azim. An experimental study of the aerodynamic interference between road vehicles[C]// SAE Paper 940422.

[5] P. Bearman, Some observations on road vehicle wakes, SAE Technical Paper series, SAE World Congress and Exhibition, Detroit, MI, 1984, 840301.

[6] D. Sims – Williams, R. Dominy, J. Howell, An investigation into large scale unsteady structures in the wake of real and idealized hatchback car models, 2001, 2001-01-1041.

[7] E. Duell, R. George, Measurements in the unsteady near wakes of ground vehicle bodies, SAE Technical Paper Series, 1993, 930298.

[8] B. R. Gilhome, J. Saunders, J. Sheridan, Time averaged and unsteady near wake analysis of cars, SAE Technical Paper Series, 2001,2001-01-1040.

[9] S. Yamamoto, K. Yanagimoto, H. Fukuda, H. China, K. Nakagawa, Aero- dynamic influence of a passing vehicle on the stability of the other vehicles. JSAE Review 18, 1997, 39–44.

[10] L. Tsuei and Ö. Savas. A Wind Tunnel Investigation of the Transient Aerodynamic Effects on a Four-Car Platoon during Passing Maneuvers[C]//SAE Paper 2000-01-0875

[11] T. Nakashima, M. Tsubokura, M. Vazquez, H. Owen, Y. Doi, Coupled analysis of unsteady aero-dynamics and vehicle motion of a road vehicle in windy conditions, Computers and Fluids, 80 2013, 1-9.

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