Aerodynamic Performance of Two-Vehicle Platooning of DrivAer Model

Jinji Li, Zhongqing Tong, Yingchao Zhang, and Tao Chen

Abstract With the gradual maturity of intelligent driving technology, driving in platoon is easy to achieve, which might benefit for energy saving. Hence, it is urgent to discover the mechanism of aerodynamic in platoon condition. Aerodynamic drag and mechanism in two-vehicle platooning in different spacing are studied by numerical method with the DrivAer model. As spacing grows, three configuration models share the same law, but the leading and trailing car appear the opposite drag change compared with that in the isolated condition. Pressure changes of some crucial parts and wake field are analyzed in detail. Some new styles of vehicle shape might be needed for driving in platoon.

Keywords Aerodynamics · Platooning · Vehicle wake

1 Introduction

Vehicle platooning has been a potential technology with the growing capabilities of vehicle autonomy and artificial intelligence in recent years [1]. A group of vehicles following each other closely has been proved a lower energy consumption strategies due to the aerodynamics performance [2]. For 2 Nissan Leafs in platoon within the spacing of one car length, the leading car always shows lower drag than trailing one and isolation condition, while the trailing one may exist higher drag than isolation at certain spacing [3]. On the other hand, Johannes et al. find that both of the two trunks undergo lower drag force than isolation, and the resistance of leading trunk exceeds the latter gradually with the distance growing up [4]. Considering these promising findings, drag reduction may depend on vehicle type and driving spacing, and the understanding of aerodynamic in 2 cars platoon needs to be further clarified.

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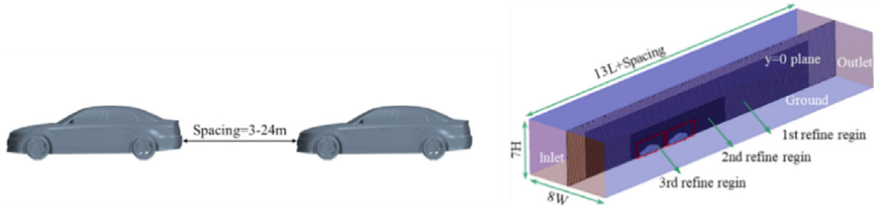


Fig. 1 Geometry and numerical set up including mesh scheme

DrivAer model, a realistic generic car model, is particularly suited to aerodynamic research due to the simplified and specific geometry characteristics [5]. In order to get relatively generic results, DrivAer model is selected in this paper. This paper aims to find out the law between the spacing of 2 cars and their drag reduction as well as the mechanism of drag variation.

2 Methodology

2.1 Numerical Set Up

DrivAer model can be divided into 3 types by different rear configurations, those Aer notchback (NB), fastback (FB) and estate back (EB), respectively. Each of the 3 full size model with smooth underbody was aerodynamic platooning simulation from 3 to 24 m spacing with STAR-CCM+ software. Inlet velocity is 120 kph, which result in Re = 1.01E+7 based on length. The boundary and mesh scheme are shown in Fig. 1. The Computational Fluid Dynamics (CFD) simulations were performed as steady RANS Realizable k–ε model with two-layer all y+ wall treatment function. The number of mesh element is 19 million.

Drag coefficient of leading vehicle (Cdl), trailing one (Cdt), average value of the Cdl and Cdt (Cda) and isolated condition (Cdi) are used to evaluate drag variation.

2.2 Simulation Validation

The Cdi and Cp are compared with the results of experiments or simulations of previous work for validation. Simulation result shows good consistency with experiment result (see Table 1). Pressure distribution discrepancy in the rear window screen is attribute to the strut for drag measurement in experiment, and they fit well in other position (Fig. 2).

Table 1 Simulation result of isolate condition compared with reference literature

Cd	NB	FB	EB
Present	0.230	0.229	0.256
Experiment [5]	0.246	0.243	0.292

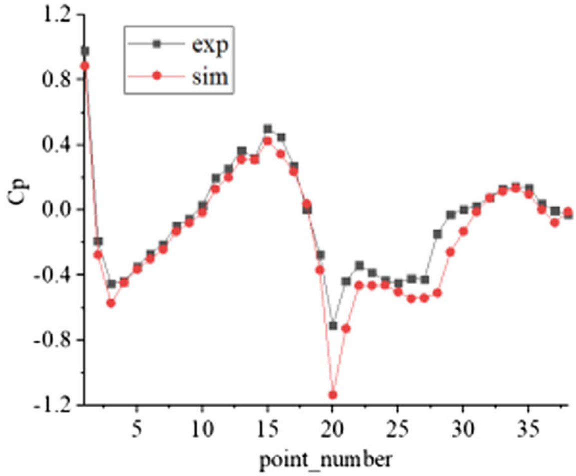


Fig. 2 Cp (pressure coefficient) distribution in y = 0 plane of notch back configuration compared with experiment of Ref. [5]

3 Result and Discussions

Law of Cd variation with different spacing is shown in Fig. 3. All of 3 back figuration models present strongly consistent: Cdt is greater than Cdl, even greater than Cdi at small distance. Then with the increase of distance, Cdt drops to less than the other two and rises gradually, but not more than them. Cdl is less than Cdi at small distance firstly, and grows gradually until it is nearly equal to isolation condition when the spacing is more than 10 m. The value of Cda is less than Cdi at all the spacing and also approach to the latter. From the Cd result in Fig. 3, we can infer that different bask seems to be no differences on effect of aerodynamic performance in platooning despite possible discrepancy on flow field.

Body is divided into 11 parts to discuss the Cd change separately. Only subtle increments in drag occur on the front parts of leading car, but significant increases

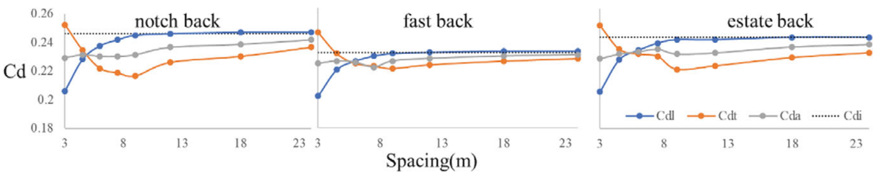


Fig. 3 Cd result of three back configurations with different spacing

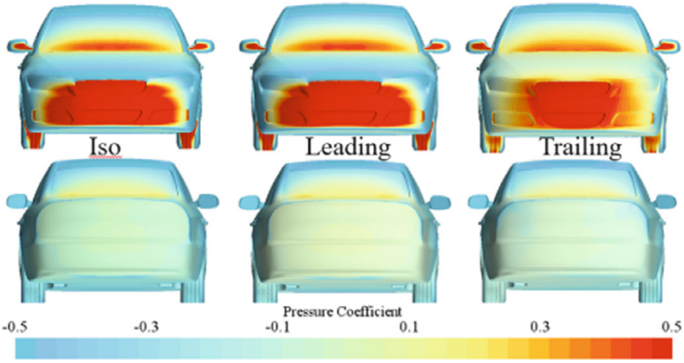


Fig. 4 Cp on the car body of isolate and 3 m spacing platoon driving condition

or decreases occur on those of trailing one. Drag on grill of trailing car decreases, however, drag on front bumper is the opposite. It is because that different parts suffer different pressure condition. As Fig. 4 shows, grill of isolate car is impacted by income flow, resulting in a complete positive pressure. However, flow separates from front window, light and front bumper parts, generating the negative pressure also accompanying with positive pressure on these surfaces. It is wake influence of leading car and the different pressure distribution that causes the different changes at front parts between the trailing and isolate car.

It is worth mentioning that hood makes a negative contribution to drag. This negative contribution is weakened greatly on the trailing car due to the early separation, slant angle and curved surface of hood, especially at short spacing. Flow passing the leading car is slowed, tilted and it concentrates on the middle region, namely the region around the grill, which is shown in Figs. 5 and 6. On the one hand, the lower speed flow impacts the surrounding position of grilling of trailing car, resulting in a lower drag at front area. On the other hand, the slant and lower speed flow avoids or delays the separation at the hood and other parts in isolate condition to great extent, which is responsible for pressure increasing of front part. Considering the position and outline of hood, separation at front of hood is beneficial to drag reduction. Hence, the hood of trailing car plays a Cd increasing part in platoon. In a word, the slow, tilted and concentrated flow, which can be summarized by "buffer effect", lead to the pressure or drag discrepancy on the front part of trailing car mentioned above. In addition, drag change of any parts in different spacing indicate that the influence caused by platooning driving is weaker with the growth of car distance. The Cd law (Fig. 3), pressure coefficient (Fig. 4), and velocity field (Fig. 5) also support this view.

In terms of wake, the shear layer at rear end of trailing car almost disappears in platoon condition, and that at the same position of leading car also weaken greatly. Moreover, shear layer at contract region rearward of the leading car body (i.e. rear wheel brow) thicken and expand outside the body meanwhile, which is shown in Fig. 7. It means that the presence of trailing car produces a buffer effect on leading

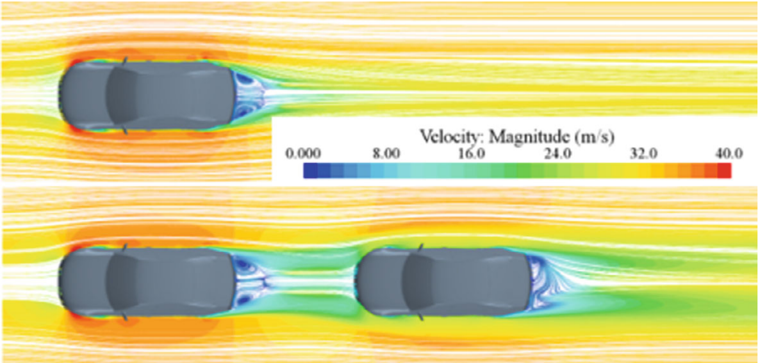
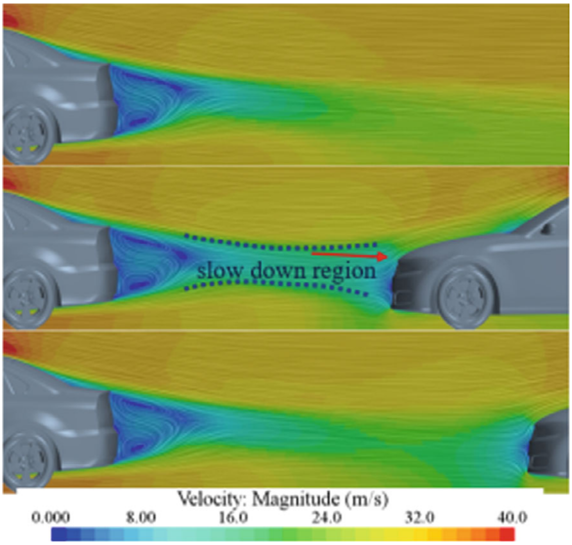


Fig. 5 Stream of isolate and 3 m spacing platoon driving condition in z = 0.035 m plane, colored by velocity magnitude

Fig. 6 Velocity vector distributions of isolate, 3 and 4.5 m spacing platoon driving condition in y = 0 plane



car. Both swirling structures in the wakes of two cars are weaken in platoon rather than isolate condition.

Shape of recirculation structures in symmetry plane in the near wake of leading vehicle in platoon in small distance condition is nearly the same as isolation one (see Fig. 5). In the wake of trailing car, no recirculation bubbles appear and symmetry state in z = 0.035 plane is broken. Despite of the distinct discrepancy, pressure at rear body of trailing car does not change a lot compared with isolate condition.

Wake changes of leading car, resulting from the buffer effect of trailing one and resulting in a higher pressure on the back of leading one, are the reason for drag reduction of leading car. In terms of value, Cd of leading car back in 3 m condition

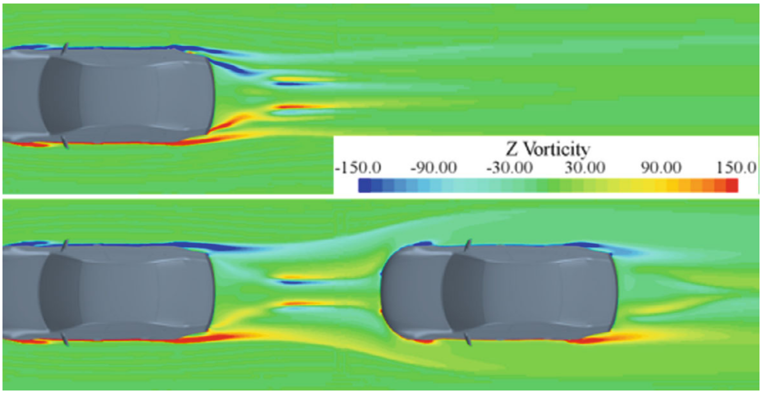


Fig. 7 Vorticity in z direction of isolate and 3 m spacing platoon driving condition in z = 0.035 m plane

is 84% lower than isolation one. This value drops to 37% and 22% in 4.5 m and 6 m condition, respectively, which means the buffer effect weakens with the spacing rising.

Integrating the advantage and disadvantage of front and wheel prat, the combining drag change could be positive or negative. In certain position, the trailing car presents a minimum drag due to the combining effect from leading one. Based on this minimum drag, shapes or accessories of car can be designed for the best income in platoon.

4 Conclusions

Aerodynamic performance of two-car platoon driving is studied. The law of wind drag and the aerodynamic mechanism is analyzed by numerical method with three configuration models. Some conclusions can be summarized as follows:

1. Vehicle of three kinds of back shows the same law Cd in two car platoon. Cda is smaller and then get close to the Cdi as spacing increase, and Cdt shows the opposite tendency to Cdl.
2. The aerodynamic drags of front parts on trailing car increase except for grill and that of the rear parts on leading car decrease. Other parts do not change obviously as much as those parts in platoon conditions. Change in Cd in platooning depends on combining consequence from each part, such as wheel and front parts.
3. The buffer effect caused by trailing car influences wake of two cars. Flow between the two car is slowed, tilted and gets concentrated. Swirling flow is weak especially in the near wake of trailing car. As spacing increases, influence of platoon driving on wake becomes weak, resulting in the drag law of spacing.

Based on the research, some new idea is needed for vehicle shape design while driving in platoon.

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