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SIDE FORCE COEFFICIENT EVALUATION OF A COMMERCIAL BUS WITH VORTEX GENERATORS

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Abstract. *Vehicle aerodynamic is field of study that more attention has been addressed to in order to reduce fuel consumption and, then, turn the desired vehicle more economically advantageous. The majority of the available work focus on drag reduction of tractor-trailers, trucks or cars, however less effort has been done to evaluate the effects on stability and on other kinds of vehicles as buses. Therefore, this work experimentally tested a commercial bus model with two different configurations using vortex generators. The results show that the side force coefficients are increased when the devices, in their respective placements, are utilized, which could jeopardize the stability of the studied bus.*

Keywords:*vehicle aerodynamic, side force coefficient, vortex generator, bus*

1. INTRODUCTION

It is unquestionable that ground vehicles are essential to modern human life. They are present in all aspects of our daily routine and there is a wide range of design with respective features, therefore it is reasonable to think that these different designs have different requirements. One aspect that could have an important role in vehicle efficiency is its aerodynamic. Indeed, the aerodynamic has a great effect in resistance to motion and stability (Hucho, 1987; Kim *et al.*, 2017b).

Some papers have shown that different add-on devices can considerably decrease drag coefficient (Altaf *et al.*, 2014; Hwang *et al.*, 2016; Kim *et al.*, 2017a). This effect may happen through some characteristics of passive flow control, such as delay of flow separation, decrease of turbulent kinetic energy and of wake intensity. In the same way, there are some studies about the influence of aerodynamic devices on driving stability that show their capacity to increase this stability. In fact, boat tail configurations showed that they can reduce side force coefficient in up to 21,91% in yawed conditions (Lee and Lee, 2017) and others great results were also achieved (Cheng *et al.*, 2019; Kim *et al.*, 2017b). However, the number of studies about the influence of aerodynamic devices on driving stability is much lesser than drag reduction. Therefore, this paper aims to elucidate more this matter. The side force coefficient behavior of a commercial bus is experimentally studied here in yawed angles up to 6°.

2. MATERIALS

The ground vehicle studied here is a Marcopolo Paradiso 1200 G7 commercial bus due to two reasons. First, because there are not many studies about buses, besides that they are blunt bodies, which could potentially favor a higher improvement than already streamlined cars. Second, because it is a very usual bus, specially in Colombia (Zuluaga *et al.*, 2017). Figure 1 presents a representative draw of the bus.

Stratasys Fortus 250 mc 3D printer machine was utilized to print the CAD model of the bus with ABSplus-P430 (Acrylonitrile butadiene styrene). The model was subdivided into three parts because its length was longer than the printer work envelope (Fig. 2). The parts were, then, united with cyanoacrylate and painted, resulting in a final model with a scale of 1:27, as it is seen in Fig. 3-4.

The two proposed configurations here use the same vortex generator in order to delay flow separation. The vortex generator used is shown in Fig. 5 and the configurations differ from the fact that one uses only one device whereas the other utilizes two devices. The respective placements are presented in Fig. 6-7. Figure 8 presents one result obtained from

Figure 1. Marcopolo Paradiso 1200 G7 bus. Available from: https://www.marcopolo.com.br/marcopolo/paradiso-new-g7-1200.

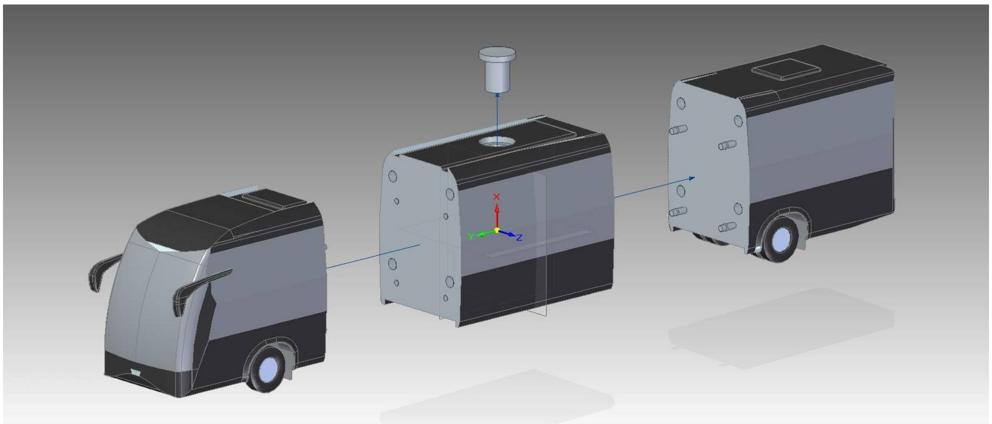

Figure 2. Model subdivided into three parts for printing.

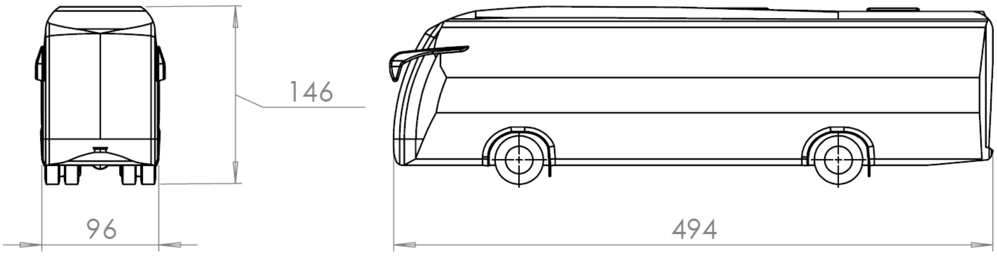

Figure 3. Schematic drawing of the bus [mm].

Figure 4. Printed model of the commercial bus.

oil flow visualization test which highlights the regions that the vortex generators want to change the flow.

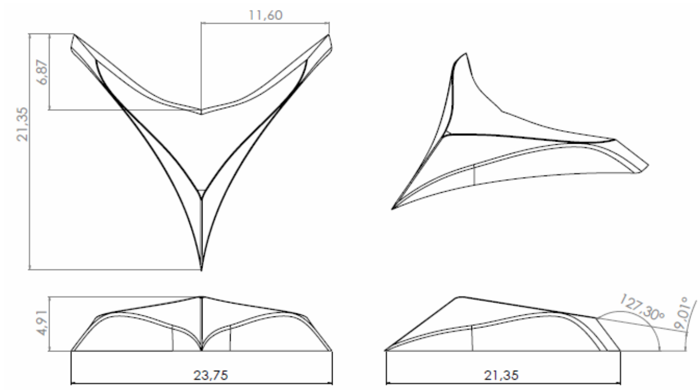

Figure 5. Schematic drawing of the used vortex generator [mm].

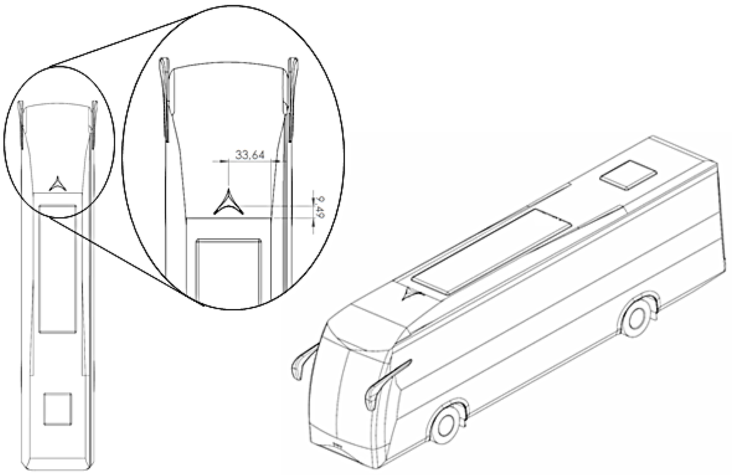

Figure 6. First configuration studied [mm].

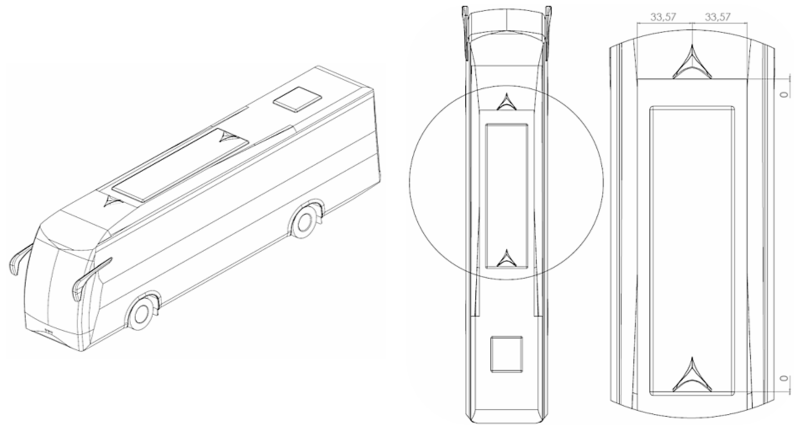

Figure 7. Second configuration studied [mm].

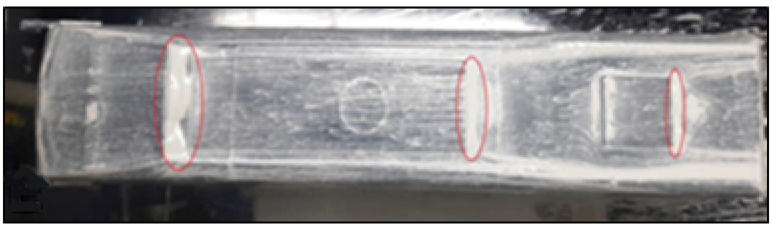

Figure 8. Oil flow visualization test presenting the regions that the vortex generators want to modify.

3. EXPERIMENTAL APPARATUS AND PROCEDURE

The tests were realized in a blowing type wind tunnel with an open circuit and closed test section at the Department of Aeronautical Engineering of the University of São Paulo (Fig. 9). Forces were acquired by a balance with a precision of 1° in positioning the angle of attack. Local temperature and atmospheric pressure were acquired by an ITWH-170 INSTRUTEMP wireless weather station. Dynamic pressure was measured with a digital micromanometer DP-CALC TSI connected to a Pitot tube. Finally, the data were presented in volts in a LabView program.

Figure 9. Wind tunnel.

In order to obtain the side force coefficients, the bus model was first tested with the wind tunnel turned off to offset the next measurements. Then, after turning it on, it was tested in different yawed angles, ranging from 0° to 6°, with $Re \approx 137000$. Finally, the data was converted to force units (N) and the coefficients were calculated through Eq (1). Figure 10 shows a diagram of this procedure. No data was correct as the model was scaled down to 1:27, which correspond to a blockage ratio of 1,8 % and the effects of model blockage on the measured data are negligible when the blockage ratio is lesser than 6 % (West and Apelt, 1982).

$$C_{sf} = 2F_{sf}/(\rho V^2 A) \tag{1}$$

Where F_{sf} is the measured side force (N), ρ is air density (kg/m^3), V is wind speed (m/s) and A is the bus front area (m^2).

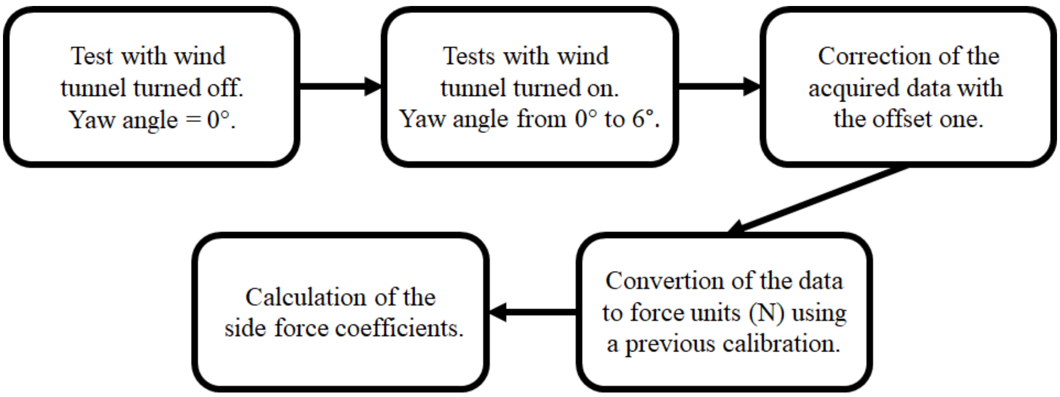

Figure 10. Diagram of the experimental procedure.

4. RESULTS AND DISCUSSION

The side force coefficients for all configurations are presented in Figure 11. It can be observed that the coefficients behave very similarly for both configurations. It is also observed that these same coefficients are greater than the baseline side force coefficient. This fact shows that the vortex generators studied here do not improve the bus stability in cross-flow winds and that an attention must be addressed to it in order to evaluate if considerable rises in yawing moments are not accomplished. Table 1 presents the values of side force coefficients.

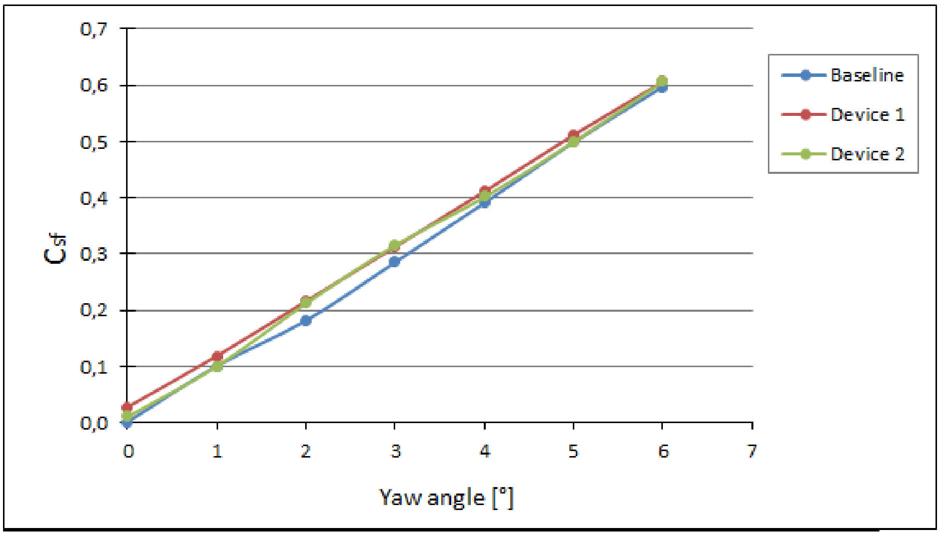

Figure 11. Side force coefficients for the baseline and both configurations studied.

Table 1. Experimental results for side force coefficients and respective differences.

Yaw angle [°]	$C_{sfbaseline}$	$C_{sfconfiguration1}$	$C_{sfconfiguration2}$
0	0.002	0.028	0.011
1	0.101	0.119	0.101
2	0.182	0.216	0.213
3	0.285	0.313	0.316
4	0.391	0.412	0.402
5	0.499	0.501	0.501
6	0.597	0.607	0.607

5. CONCLUSIONS

This work presents an experimental study about vehicle aerodynamic. A commercial bus was tested to observe the influence of vortex generators on side force coefficient and it was observed that, under the studied conditions, the devices increased the side force and, then, could jeopardize the stability of the vehicle. It is discussed that this may have happened due to a more complex flow structure that was created behind the device that was absent before.

More studies should be developed to understand the full behaviour of the flow, probably utilizing computational fluid dynamics and other experimental apparatus. In this way, the specific device and its placement would be better known.

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