

PROPOSAL OF AN AERODYNAMIC CONCEPT FOR AUTOMOTIVE DRAG REDUCTION

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Abstract. *The automotive industry pursues to decrease the fuel consumption of road cars. As the Brazilian government, many countries around the world incentives the industry to achieve such reduction. The purpose of this paper is an aerodynamic concept for drag reduction. To represent a car model, the DrivAer Fastback two-dimensional profile has been adopted as baseline. The injection and suction of momentum by a jet applied on the car rear are investigated by means of CFD. From the quantitative point of view, the suction jet on rear car profile does not seem to be a way to yield drag reduction. The injection jet at higher speed points to smaller global drag than baseline profile. Despite this positive first conclusion, the correction of drag results (removing the jet momentum from the global drag) points to higher drag of profile car than the baseline car in all three cases. On the other hand, the results from the injection of momentum at lower speed suggest a reasonable application as drag reduction system. Compared to the baseline car profile, momentum injection cases at all positions indicates drag reduction. In addition, the profile drag decreases as the jet position is higher at lower jet speed. Therefore, the main contributions of this paper is (a) to expose that the best drag reduction has been evidenced via injection at lower speed at higher rear car position, as well as (b) offering to automotive engineering an aerodynamic concept to improve drag reduction of road cars.*

Keywords: *Aerodynamic Concept, Automotive, DrivAer, Passive system, Injection.*

1. INTRODUCTION

For road cars, one of the major area of development in aerodynamics is concerning drag force. The reason is that drag affects directly on the fuel consumption. Once the flow detaches behind the rear of the vehicle, it generates a turbulent wake. As it intensifies, drag increases over the car, although it has non-linear relations to turbulent wakes (Hucho, 1998). Thus, aerodynamics devices have been employed to reduce such effects.

The motorsport gives remarkable examples of aerodynamic devices. Over recent years, the predominant difference between the teams of Formula 1 championship was precisely the development work on aerodynamic mechanisms. In 2009, the Brawn GP team developed its “double-diffuser” version to race cars, which provided such an advantage over its rival teams, rendering the driver and constructor championship titles of that year. In 2010, the “F-duct” (based on the same principle of momentum injection) allowed the McLaren team to reach the deputy championship title of that season. In 2012, despite a fourth place in the construction championship, Mercedes team showed the potential of its innovative aerodynamic device (Double Drag Reduction System – DDRS); also, it used the principle of momentum injection, on both front and rear wing.

On this line of aerodynamic system, this paper proposes an aerodynamic concept for automotive drag reduction. It is based on transferring momentum by injection and/or suction jet. The objective is to reorder the vortex structures at turbulent wake behind the rear car model.

2. BACKGROUND

In previous studies, Soares *et al.* (2014a,b) presented injection of momentum by jet as an effective method to achieve reattachment of boundary layer over aerofoils. One of the reason to explain such phenomenon is the influence of the additional turbulent kinetic over the aerofoil surface. As the air leaves the slot, it interacts with the flow over the aerofoil. This interaction generates vortices that increase the turbulent kinetic energy. As consequence, the flow keeps energised enough to delay its separation from the aerofoil upper surface.

Unfortunately, cars usually have massive detachment backwards. As one of the most cited experiments in automotive aerodynamics, a generic car-type bluff body known as Ahmed body (Ahmed, 1983) indicates that approximately 85% of the drag comes from the wake region behind the model.

Regarding the turbulence model to deal with such flow phenomenon, Browand *et al.* (2009) shows that few models have reasonable accuracy for drag prediction: SST $k-\omega$ (0.8%), High-Reynolds Number $k-\epsilon$ (1%), and RNG $k-\epsilon$ (2.3%), comparing to experimental result. Nonetheless, according to Olander *et al.* (2011), the realizable $k-\epsilon$ turbulence model is used in the standard procedure at Volvo cars throughout their computational aerodynamics development.

3. MATHEMATICAL MODELS

A Reynolds-Averaged Navier Stokes (RANS) approach has been adopted in this investigation. For cases of incompressible, steady-state flow, the conservation of mass and Navier-Stokes equations are adopted.

The numerical simulations are carried out using the STAR-CCM+ code, employing the Realizable k-ε two-layer model in steady-state, LSQ 2nd-order gradient method. Since there is no experimental data from this model in two-dimensional domain, there is no specific Reynolds number to be set. Hence, the free stream of $U_\infty=40$ m/s is chosen to better fit a real car operation. The air density (ρ) is 1.18415 kg/m³ and its dynamic viscosity (μ) is 1.85508x10⁻⁵ N.s/m².

The DrivAer model has been chosen as baseline in this investigation. Due to time constraints, the computational domain of all simulations were two-dimensional. The symmetry section of DrivAer Fastback model (Heft *et al.*, 2012a,b) of 1:1 scale has adopted for studies. The inlet of rectangular domain is positioned 2L upstream of the car profile, the ground is 12L long, and is 0.065L from the front wheel axis position.

The jet properties are the same as if the freestream. The channel has a gap of 20 mm and the height of hole on the car surface is 400 mm, 640 mm or 900 mm, from the ground level. The injection jet is positive in the X direction, and suction is negative likewise. Tables (1) and (2) present the physical model setup and boundary conditions, respectively.

Table 1. Physical model.

Domain	Time	Fluid	Flow solver	Equation of State	Flow Regime	Turbulence model
Two-dimensional	Steady-state	Air	Segregated	Constant density	Turbulent	Realizable k-ε two-layer

Table 2. Boundary conditions applied over the domain.

Boundary	Condition
DrivAer car profile	wall: no slip
Inlet	velocity-inlet: $U_\infty = 40$ m/s, $I = 0,1\%$, $\mu_t/\mu = 10$
Outlet	pressure-outlet
Top	Symmetry
Ground	wall: no-slip, ground movement of $U_w = 40$ m/s
Slot – wall	wall: no slip
Slot - inner section	velocity-inlet: $U_j = 10$ m/s or 20 m/s, $I = 0,1\%$, $\mu_t/\mu = 10$ velocity-outlet: $U_j = 10$ m/s or 20 m/s, $I = 1\%$, $\mu_t/\mu = 10$

4. RESULT ANALYSIS

An important fact is that the transferring momentum (via injection or suction) may lead the code to miscalculate (under or overpredicting) the drag based only over the profile. Thus, based on the Navier-Stokes equations, the real profile drag coefficient is obtained by removing the injection (or suction) momentum from the global drag coefficient achieved, as seen in Eq. 4. The drag coefficient correction (C_{jet}) is normalized as the drag coefficient profile.

$$C_{D\ profile} = C_{D\ global} - C_{jet} = \frac{F_D}{\frac{1}{2} \rho_\infty A_{ref\ car} U_\infty^2} - \frac{\rho_{jet} A_{ref\ slot} U_{jet}^2}{\frac{1}{2} \rho_\infty A_{ref\ car} U_\infty^2} \quad (4)$$

The correction of obtained results has been done. Figures (1) and (2) show the global drag (achieved as an output from the solver) and the corrected drag, which takes into account the additional jet momentum.

From a quantitative point of view, the suction jet on rear of the DrivAer car profile does not seem to be a way to yield drag reduction. Suction on car rear with jet speeds of 10 m/s and 20 m/s do not affect the car profile drag. Thus, the changes in global drag in relation to baseline presented in Figs. (1) and (2) are only due to the portion of jet momentum. Moreover, by observing Fig. (4), it is noticed that the wake region is still similar to turbulent wake of the baseline configuration.

Regarding the injection method, the global drag coefficients from cases of jet at higher speed (20 m/s) would lead to conclude that such case is useful for drag reduction. However, since the drag prediction is corrected (taking into account the jet momentum), all three cases actually display profile drag higher than the baseline model. In summary, injections at higher speeds (20 m/s) are inappropriate for drag reduction purpose in the model studied.

Despite the injection at higher speed, the jet at lower speed (10 m/s) provides a valuable conclusion. On the other hand, the results from injection of momentum suggest a reasonable application as drag reduction system for lower jet speed (10 m/s). In all positions of this cases indicates reduction compared to baseline car profile. In addition, the profile drag decreases, as the jet position is higher.

Finally, the best situation achieved a real reduction in the drag coefficient by 5 counts for the profile drag, and 7 counts for the global drag (by assuming inner generation of gas, like escape gases from the engine).

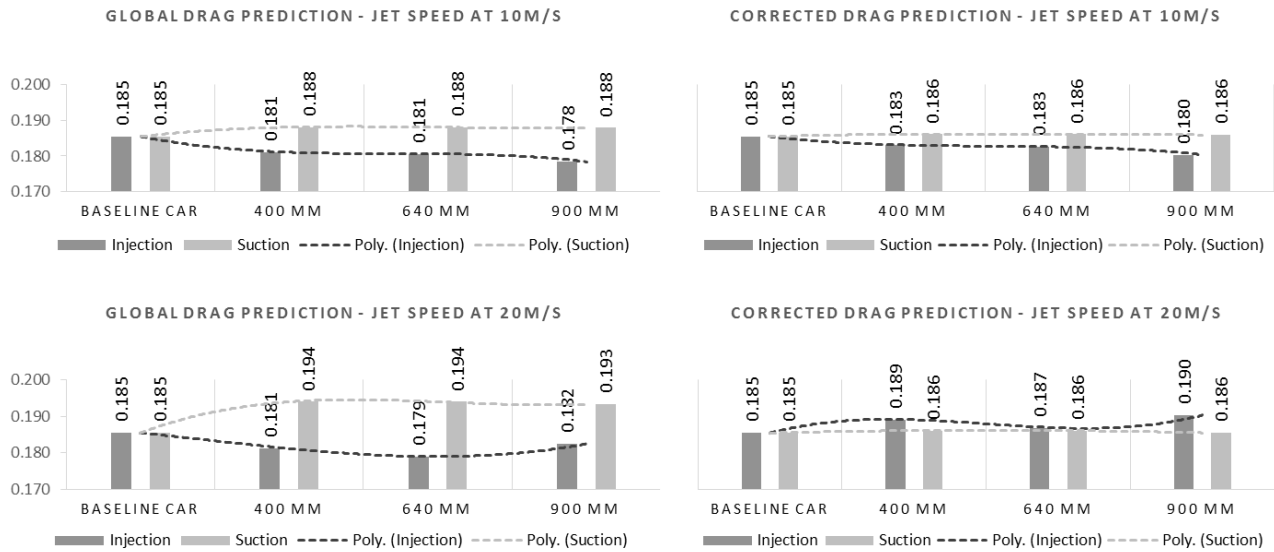


Figure 1. Global drag (left) and corrected (right) coefficient over the car profile, with jet speed at 10 m/s and 20 m/s.

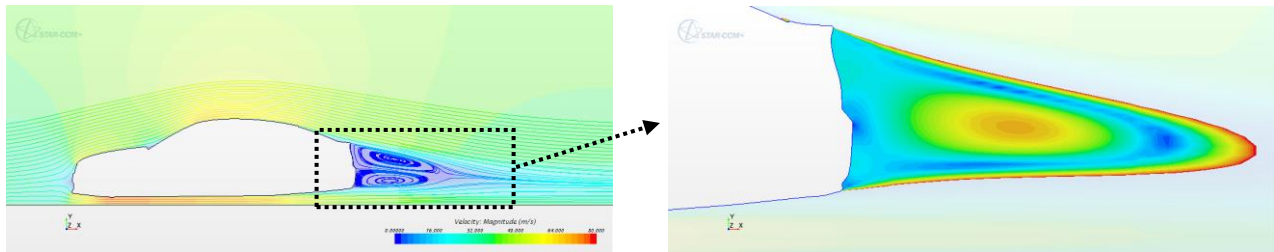


Figure 2. Streamlines over the DrivAer Fastback baseline profile at 40 m/s (left), and wake region behind its rear (right).

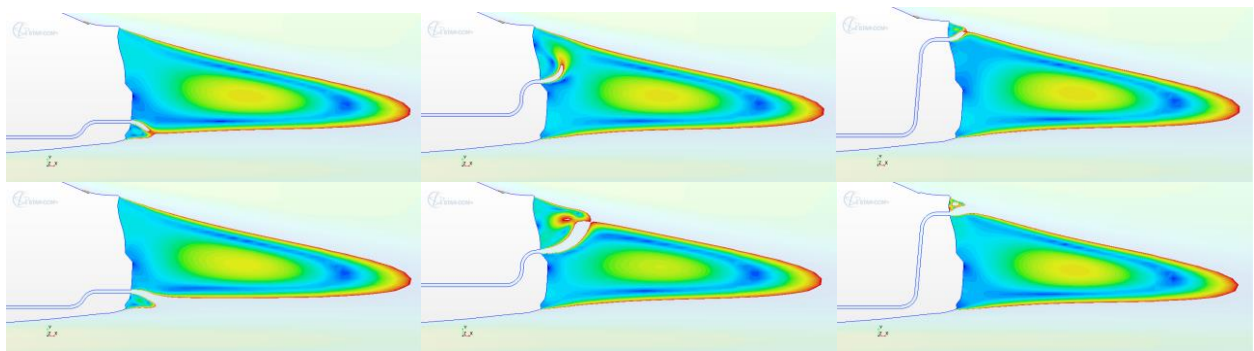


Figure 3. Comparison of wake region of DrivAer Fastback profile by velocity field, under injection jet at 10 m/s (above) and 20 m/s (below). The height of slots jet are 400 mm (left), 640 mm (middle), and 900 mm (right).

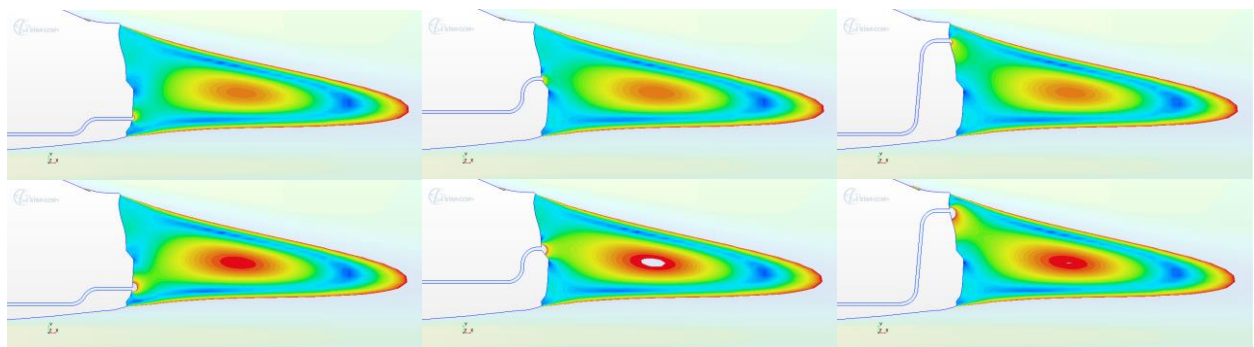


Figure 4. Comparison of wake region of DrivAer Fastback profile by velocity field, under suction jet at 10 m/s (above) and 20 m/s (below). The height of slots jet are 400 mm (left), 640 mm (middle), and 900 mm (right).

5. INTRODUCTION OF A ROAD CAR AERODYNAMIC CONCEPT

The previous section indicated that injection momentum at the wake region can reduce the drag of a vehicle. Nonetheless, such injection and/or suction at rear car does not necessarily have to be by a forced or active system. A representative sketch of this concept is shown in Fig. (5). It purposes that such rear jet would occur as passive system by collecting air from:

- (i) car areas of higher pressure than rear car surface; or
- (ii) regions of higher momentum in the X-axis direction to overcome the adverse pressure throughout the collection channel, as underbody inlets.

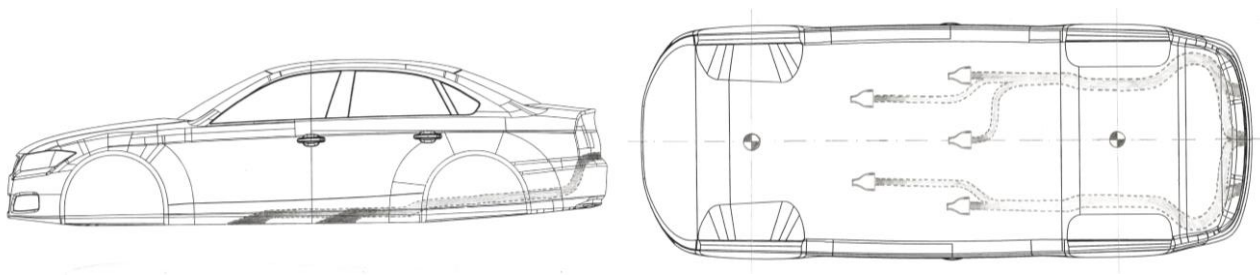


Figure 5. Side and bottom views sketch of passive aerodynamic system concept over DrivAer model.

6. CONCLUSION

A proposal of aerodynamic concept for automotive drag reduction has been presented in this paper. In addition, a numerical investigation has been performed. The objective is to identify the potential of injection and suction methods of momentum over the wake region of the car model. In summary, three different heights of rear jet, two jet speeds, and two methods has been tested.

The suction jet method on rear of the DrivAer car profile does not seem to be a way to yield drag reduction, either at higher or lower jet speed. Thus, the changes in global drag are only due to the portion of the jet momentum.

The injection jet at higher speed point to smaller global drag than baseline profile. Although this positive first conclusion, the correction of drag due to jet momentum, all three cases actually display profile drag higher than the baseline model. In other words, the injection jet at higher speed is inapposite for drag reduction purposes, when compared to the baseline DrivAer Fastback profile.

On the other hand, the results from injection of momentum at lower speed suggest a reasonable application as drag reduction system. All positions of this case indicates reduction compared to baseline car profile. In addition, the profile drag decreases as the jet position is higher.

Therefore, the main contributions of this paper is (a) to expose that the best drag reduction has been evidenced via injection at lower speed at higher rear car position, as well as (b) offering to automotive engineering an aerodynamic concept to improve drag reduction of road cars.

7. REFERENCES

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8. RESPONSIBILITY NOTICE

The authors are the responsible for the information included in this paper.