Influence of warning lights for intervention vehicles on aerodynamic performance

D Ioza, L Ilea and G Fratila

Road Vehicles Department, University Politehnica of Bucharest, Bucharest, Romania

E-mail: laurentiu.ilea@yahoo.com

Abstract. In today’s world, the freedom to travel is a daily necessity and part of human rights. This premise is directly linked to transport sector causative of air pollution. While the focus is on heavy transport and passenger vehicles, another important segment is represented by special utility vehicles such as the ones for intervention purposes (police, ambulance, etc.). The mandatory presence of warning lights bars has a big impact in aerodynamic performance and hence, in their emissions. The paper studies the influence of a generic lights bar on sedan, hatchback and SUV body types, in three main roof mounting positions – front, median, rear. Through CFD methods it is found that the most unfavourable case is the front mounted lights bar with 6g up to 12g CO₂/km (WLTP conditions). The influence of median and rear mounting position is smaller, but still adds 3g to 7g CO₂/km. Using streamlines, pressure and shear forces, future work will focus on optimizing the lights bar shape and size, for a reduced SCx impact in overall performance. This topic is considered very important since main cities (including Bucharest) started taxing or banning high pollution vehicles.

1. Introduction

While for most of us distance is measured in kilometres and sometimes hours, it should also be measured as a CO₂ footprint of our liberty to move. In this context, all vehicles, regardless of their purpose must comply with a set of well-defined rules imposed by legislation. The auxiliary equipment required for intervention vehicles increase the declared emissions for the standard vehicle through mass, aerodynamic force and electric consumption. As the local authorities start to strictly regulate central areas for cleaner air [1], the paper proposes to study the influence of a generic lights bar on passenger vehicle’s aerodynamic coefficient and the possible ways to reduce it.

2. Method of study

The subject is studied using the Computational Fluid Dynamics (CFD) method due to its numerous advantages such as: low investment, relative short time to obtain results, possibility to fine-control test conditions, multiple iterations, and lack of real-life constraints. On the other hand, it should not be overlooked that the chosen mathematical model, the used software and the CFD error can influence the results’ accuracy. Based on these criteria, the aerodynamic influence of the lights bar installed on the vehicle is assessed using a software based on Lattice-Boltzmann statistical method [2],[3].

Limit conditions are imposed in order to simulate a real-life wind tunnel environment. The chosen air speed is 45.83 m/s, value correlated with wind tunnel dimensions and legislative requirements. The environment is discretised by volume method, with the finest grid near the study object (1 elementary cell 1.2x1.2x1.2 mm). The study objects are different vehicles body types (figure 1) with an accurate
3D representation, while the lights bar (figure 2) was arbitrary chosen considering their diversity, depending on manufacturer, purpose and user guidelines.

![Figure 1](image1.png)  
**Figure 1.** 3D model of studied vehicles.

![Figure 2](image2.png)  
**Figure 2.** 3D model of lights ramp chosen for CFD assessment.

Due to the possibility of mounting the lights bar in arbitrary positions (depending on the mounting support, type of vehicle and general purpose), the study is done for three primary situations: advanced position (case A), median position (case B) and rear position (case C), as indicated in figure 3.

![Figure 3](image3.png)  
**Figure 3.** Primary positions defined for mounting the lights bar.

### 3. CFD results and analysis

Using the described 3D models presented under point 2 above, CFD simulations were prepared for the three mounting positions on each body type vehicle, plus the reference without the lights bar installed.

The post process was performed by extracting the product between the aerodynamic coefficient, Cx and the frontal surface of the vehicle, S, measured in m². This form is chosen so results can be compared since the frontal area is different for the three vehicles. The other input parameters like air density and air speed have the same standardised values for all studied cases.

The obtained CFD results are resumed in table 1, 2 and 3, for each specific body type.

| Studied case | L | L - A | L - B | L – C |
|--------------|---|------|------|------|
| SCx [m²]     | 0.659 | 0.905 | 0.753 | 0.796 |
| Δ SCx [m²]   | -  | + 0.246 | + 0.094 | +0.137 |
| Δ SCx [%]    | -  | + 37 | +14 | +20 |

**Table 1.** CFD results for L body type 3D model.

| Studied case | B | B - A | B - B | B – C |
|--------------|---|------|------|------|
| SCx [m²]     | 0.836 | 0.996 | 0.910 | 0.905 |
| Δ SCx [m²]   | -  | +0.160 | +0.074 | +0.069 |
| Δ SCx [%]    | -  | +19 | +8.8 | +8.2 |

**Table 2.** CFD results for B body type 3D model.
Table 3. CFD results for SUV body type 3D model.

| Studied case     | SUV    | SUV - A | SUV - B | SUV – C |
|------------------|--------|---------|---------|---------|
| SCx [m²]         | 1.000  | 1.127   | 1.059   | 1.059   |
| Δ SCx [m²]       | -      | +0.127  | +0.059  | +0.059  |
| Δ SCx [%]        | -      | +12     | +5.8    | +5.8    |

As anticipated, a comparison with the reference SCx indicates that the L body has the best aerodynamic performance, while the SUV body has the biggest SCx value [4]. The principal factors are shape and size of rear face of the body and the riding height, which influence the rear wake energy level. For the least amount of lost energy, the wake should be equilibrated and as reduced as possible in size [5]. The wake for the reference vehicles is presented in figure 4.

![Rear wake represented by stream lines and velocity magnitude.](image)

**Figure 4.** Rear wake represented by stream lines and velocity magnitude.

When the lights bar is added, the SCx value increases from +5.8% to +37% depending on vehicle type and mounting position. It can be observed that the biggest influence is registered for the L body type, with the police ramp mounted in the advanced position. As seen in figure 5, the air flow is highly turbulent because the ramp is placed in the direct path of high-speed air flow coming from the windshield. This technical definition will induce an increase of approximatively +12g CO₂/km. From the analysis it results that for the L body the best alternative is the median mounting position, with a plus of +0.094m² in SCx and +5g CO₂/km. In this case, the ramp is not in the path of high-speed windshield air flow, so the associated wake is not added to the rear wake. The rear mounting position will bring +6.5g CO₂/km.
Applying the same analysis on B type body, it can be observed that the lights ramp brings a degradation between +8.2% (case B-C) and +19% (case B-A), as presented in table 2. It should be mentioned that the median and rear mounting positions can be treated as having the same results. This conclusion arises due to small SCx difference, taking into account also the CFD error.

In figure 6 it can be easily observed that the wake for the advanced mounting position of the ramp is approximately double in size as compared with median and rear mounting positions. The B-A configuration increases the emission with +8g CO₂/km, while B-B and B-C configurations can be associated with an increase of +3.5g CO₂/km. This is because the lights bar wake has a small influence on rear wake dimensions for the B-B and B-C cases.

It can be concluded that the lights bar influence on SCx value is more reduced, with an overall CO₂ difference of 1.5g CO₂/km for best case scenario and 4g CO₂/km for worst scenario between B and L. This is because B body vehicles generally have a worse wake that the L body vehicles.
It is foreseen that, if the chosen lights bar is mounted on a vehicle with a better SCx performance (L body in our case), a greater impact will be obtained as compared with the case when the lights ramp is mounted on a vehicle with worse SCx performance (B body in our case). This hypothesis is confirmed by the 3rd analysed body shape, the SUV.

In reference with standard SCx (no lights bar mounted), the CFD results exposed in table 3 indicate that, as for B body shape, the C-B and C-C are the best-case scenarios with an increase of just 5.8%. This can also be expressed as +0.060 m² for SCx value and +3g CO₂/km, which means it is the lowest impact registered in current study. Case C-A brings a degradation of +0.127 m² or +6.35 CO₂/km. The airflow behaviour is similar with previous analysed cases, as it can be seen in figure 7.

![Figure 7. Vorticity magnitude for L body with lights bar.](image)

4. Conclusions

The CFD results for the generic chosen vehicle body types confirms that the L shape SCx has the best value (0.659 m²), followed by B shape SCx (0.836 m²) and SUV shape (1.000 m²). This first set of results is considered a validation of Lattice-Boltzmann mathematical method and of the generic imposed limit conditions for the performed simulations. Also, the values should be interpreted by taking in consideration also the 2.5% CFD error that might occur due to different factors like convergence quality, local geometry refinement, etc. It is highlighted that the present study has the purpose of assessing the influence of a light bar on SCx value of a standard vehicle body and is not focused on the absolute SCx value of the vehicle.

The obtained SCx values for the influence of the light bar indicate that middle and rear mounting positions should be used as they have the smallest impact on B and SUV bodies (+0.059m²...0.074m²). The exception is the L body where the rear mounting position has a bigger degradation than the central position (+0.137 m² as compared to + 0.094 m²).

It is highlighted that, in the context in which vehicle emissions must be reduced, with special attention focused on central urban areas, intervention vehicles (which must be equipped with lights bar for alert purpose) must be specially optimised. The present study results show extra emissions of +3g CO₂ for best case scenario and +12g CO₂ for worst case scenario, values which must be taken in consideration for influence on air quality, in urban areas especially.

The study will continue by optimising the shape of the lights bar in order to reduce the values for all scenarios. This can be achieved through the shape of the lights bar but also by applying special...
aerodynamic elements like optimised wheel deflectors. The final purpose is to bring the lights bar degradation as closest to SCx reference level as possible.

5. References

[1] Holman C, Harrison R and Querol X 2015 Review of the efficacy of low emission zones to improve urban air quality in European cities *Atmospheric Environment*, Volume 111

[2] Ricot D 2016 Turbulent flows using Lattice Boltzmann Method application on automotive configurations *MUSAF 16*, ONERA, Toulouse

[3] Qian Y H, D’Humanieres D, Lallemand P 1992 Lattice BGK Models for Navier-Stokes Equation, *Europhys Let. 17*

[4] Andreescu Cr, 2011-2012 Dinamica autovehiculelor, curs, dept. Autovehicule Rutiere, Facultatea Transporturi, UPB

[5] Hucho W-H, 1998 Aerodynamics of road vehicles, 4th edition, *SAE*, ISBN 0-7680-0029-7