Computational Study of the Front-end Downforce Enhancing Aerodynamic Elements in Sports Cars

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Research

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Computational study of the front-end downforce enhancing aerodynamic elements in sports cars

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ABSTRACT

While designing sports cars, getting the aerodynamic balance of the vehicle is very important. Aerodynamic elements to create rear downforce are studied extensively while, this research tries to recognize the various ways of developing effective front end down force producing devices. The most widely used add-on devices include the front splitter, canards and underbody vortex generators. CFD simulations are employed to study these devices on the widely acknowledged MIRA fastback model. ANSYS Fluent CFD software was used with the efficient k- ϵ model to get accurate results while avoiding expensive experimentation costs. Reduction in lift force with the help of these elements generally leads to high drag force. This study aims to find out the most suitable and versatile devices. The average lift decrement on the addition of front aerodynamic elements was $\Delta C_l = 0.0778$ while the increase in drag was $\Delta C_d = 0.0393$.

Keywords: Aerodynamics, downforce, drag, ANSYS

1 INTRODUCTION

Most of the research on improving down force of sports cars focuses on the rear aerodynamic elements such as rear wings and rear diffusers. But the literature concerning the front aerodynamic elements is not available readily. Front end aerodynamic elements such as front splitter (or front diffuser), canards and front-end underbody vortex generators are used in motorsports and expensive sports cars to provide front axle down force. The front splitter (fitted below the front bumper) reduces

lift by producing low pressure under the vehicle's front end by acting as barrier for the incoming air. Furthermore, the wind is collected on the splitter making high pressure zone above it to increase the down force effect. Canards are attached to both sides of the front bumper and designed to direct the air upwards. Canards are also designed specially to direct air flow over the front wheels on the side of the vehicle which helps reduce drag. Optimizing the canards design is a tedious operation and motorsports teams spend a lot of time and effort perfecting it [1,2]. Under-body vortex generators are designed in a way to direct the air through the side of the car in the form of vortices which creates low pressure under the vehicle. Vortex generators are underbody add-on devices and therefore don't affect the aesthetics of the vehicle. Creating a suitable aerodynamic balance of sports cars is very important especially if different race tracks are concerned. Nowadays, adjustable devices are used to optimize performance in different driving conditions [3,4]. For example, front splitters can be adjusted by altering the lip reach and height. Ahmed et al. [5] studied the flow structure of a basic 3-D bluff body known as the Ahmed body and found the flow to be highly unsteady and three-dimensional. Another acknowledged model is the MIRA fastback model which is used in this study. Zhang et al. [6] investigated this model's aerodynamic properties both experimentally and with the help of Computational Fluid Dynamics (CFD) simulation method. This study is an extension of the MIRA fastback model with the addition of front aerodynamic elements. When the vehicle is travelling at high speeds, the ground effect significantly affects the car's aerodynamics, especially with front diffuser and underbody vortex generators. The aim is to study only the direct pressure changes caused by the add-on devices to understand the main reasons for the increase in down force and mimic wind tunnel testing.

2 MODELLING

1:8 MIRA fastback model is used for this research. The model has 520.63 x 203.125 x 177.625 mm dimensions as taken from Zhang et al. [6]. Solidworks 2019 computer aided design (CAD) software was used to design the model. Front splitter, canards and vortex generators were then added to the model.

Fig 1. MIRA fastback model

Fig 2. MIRA fastback model side view

Fig 3. Model with attached front splitter

Fig 4. Model with front splitter bottom view

Fig 5. Model with attached canards

Fig 6. Model with canards top view

Fig 7. Model with attached underbody vortex generators

Fig 8. Model with vortex generators bottom view

3 SIMULATION

3.1 Methodology

Numerical simulations are a great way to avoid experimental costs but still provide accurate and reliable results. Steady-state Reynold's Averaged Navier-Stokes (RANS) was used for the current simulation since the road cars are low Mach number transportation and steady aerodynamic characteristics are needed to be studied. The realizable $k-\epsilon$ model was selected as it produces accurate results.

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[\frac{\mu_t}{\sigma_k} \frac{\partial k}{\partial x_j} \right] + 2\mu_t E_{ij} E_{ij} - \rho \varepsilon$$

$$\frac{\partial(\rho \varepsilon)}{\partial t} + \frac{\partial(\rho \varepsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[\frac{\mu_t}{\sigma_\varepsilon} \frac{\partial \varepsilon}{\partial x_j} \right] + C_{1\varepsilon} \frac{\varepsilon}{k} 2\mu_t E_{ij} E_{ij} - C_{2\varepsilon} \rho \frac{\varepsilon^2}{k}$$

$$\sigma_k \equiv 1.0, \sigma_\varepsilon \equiv 1.2, C_2 \equiv 1.9$$

Here the turbulence kinetic energy is given by k and the dissipation rate of turbulence energy is given by ε . S is the modulus of the mean rate-of-strain tensor, P_k is the shear production of turbulent kinetic energy, ν_t is the turbulent eddy viscosity and ν is the kinetic viscosity.

In this study, aerodynamic force coefficients namely drag and lift coefficients are calculated to describe the aerodynamic characteristics of different models.

$$\text{Drag coefficient: } C_d = F_x / 0.5 \rho v^2 A$$

$$\text{Lift coefficient: } C_l = F_y / 0.5 \rho v^2 A$$

Where F_x is the aerodynamic drag force, F_y is the aerodynamic lift force, ρ is the air density (1.225 kg/m³), A is the frontal area, v is the incoming air velocity (27.78 m/s in the present study).

3.2 Simulation setup

Simulation is performed with the help of ANSYS Fluent 19.2 CFD software. To mimic wind tunnel results from Zhang et al. [8], the enclosure is constructed keeping in mind the distance between the vehicle and ground (of 50 mm). The respective models are enclosed in suitable enclosures and named selections are applied to the sides (fig 9).

Fig 9. Enclosure

Tetrahedral unstructured meshing with a minimum element size of 40 mm is done which is a relatively coarse mesh to achieve faster calculations with satisfactory results. 5 mm mesh sizing is applied on the vehicle surface since accurate results are required in the vicinity. A total number of 118761 nodes and 626013 meshed elements were formed.

Fig 10. Meshed model

Table 1. Simulation parameters

S. No.	Settings	Parameters
1	Simulation region	4 x 1.6 x 1.2 m ³
2	Blockage ratio	1.875 %
3	Free stream velocity	27.78 m/s
4	Re	9.18 x 10 ⁵
5	Turbulence intensity	< 0.5 %

Frontal area of the MIRA fastback model resulted in a blockage ratio of 1.875 % which is less than 5 % and hence the blockage effect can be neglected, Farell et. al. [7]. The solution algorithm for the simulation was based on SIMPLE algorithm for the iterative solution of the steady RANS equations. Table 2 shows the different boundary conditions applied to the model.

Table 2. Boundary conditions

Name	Condition	Slip or no- slip	value
vehicle surface	wall	No-slip	/
inlet	Inlet-velocity	/	27.78 m/s
outlet	Pressure outlet	/	0 Pa
ground	wall	No-slip	/
walls	wall	Slip	/

3.3 Validation

The simulation results should be validated with experimental results. Drag coefficient of MIRA fastback simulated in this research was obtained to be 0.295. Zhang et al. [8] and Wang et al. [9] carried out wind tunnel tests on MIRA fastback model and achieved 0.286 drag coefficient which corresponds to a 3.2 % error (within experimental engineering error of 5 %).

4 RESULTS

Table 3. Aerodynamic force coefficient results of different models

	C_d	C_l
Fastback	0.2952	0.0410
with front splitter	0.3987	-0.1247
with canards	0.2913	-0.1290
with vortex generators	0.3136	-0.1028

From the results in table 3, it is evident that canards help increase the most down force while not increasing drag by a significant amount. Front splitter reduces lift drastically as well, but the sacrifice is the high drag force that the vehicle has to endure. The lift force in the model with vortex generator was reduced by a considerable margin but not as much as canards and with a small amount of increase in drag.

Fig 11. C_d and C_l

(a) MIRA fastback model

(b) Front splitter

Fig 12. Velocity distribution along the longitudinal symmetry plane.

Fig 12 shows the difference of velocity distribution of the basic model (a) and model with front splitter (b) which shows the splitter prohibiting air from getting under the vehicle. The wake behind the vehicle is also deformed.

(a) MIRA fastback model bottom view

(b) Model with front splitter bottom view

(c) Model with front splitter

Fig 13. Pressure contours

The difference between fig 13 (a) and (b) clearly depicts the pressure drop behind the splitter which creates downforce. Similarly, fig 13 (c) shows the high-pressure build-up on the front splitter lip which adds to the down force effect.

Fig 14. Velocity distribution for canards at longitudinal plane 105 mm from centre

Fig 15. Pressure contours on canards model

Fig 15 shows a basic canards model being studied. The canards are smooth lightweight plates generally placed at an angle of $15 - 30^\circ$ with the horizontal. As evident from fig 14, 15 the airflow is directed upwards, creating low pressure zone behind the canards and a relatively high-pressure zone on it, consequently creating down force.

Fig 16. Vortex generators 0.03608078

Fig 17. Pressure contours of model with vortex generator (bottom view)

It directs the air flow away from the under carriage and creates low pressure zone below as evident in fig 17.

5 CONCLUSIONS

The results show that canards increase the most down force with the least increment in drag. The problem with road legal sport cars is the ground clearance. Big speed bumps and uneven road surfaces limit the size of front splitters and vortex generators. Similarly, Canards are in the blind spot and generally made of expensive carbon fibre material which can be damaged on contact with other vehicles or objects. Front splitter increases the frontal area of the vehicle which increases the drag

force. The average lift decrement on the addition of front aerodynamic elements was $\Delta C_l = 0.0778$, while the increase in drag was $\Delta C_d = 0.0393$. The numerical results also revealed that the k- ϵ model is a reliable method for simulating the flow field. Future scope of improvements may include experimental and numerical analysis of elements with improved designs and inclusion of the ground effect.

DECLARATIONS

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Authors' contributions

This is the author's individual effort. Author has read and approved the final manuscript.

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Availability of data and materials

All data generated or analysed during this study are included in this article with appropriated citations.

Competing interests

The author declare that he has no competing interests.

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Figures

Figure 1

MIRA fastback model

Figure 2

MIRA fastback model side view

Figure 3

Model with attached front splitter

Figure 4

Model with front splitter bottom view

Figure 5

Model with attached canards

Figure 6

Model with canards top view

Figure 7

Model with attached underbody vortex generators

Figure 8

Model with vortex generators bottom view

Figure 9

Enclosure

Figure 10

Meshed model

Figure 11

C_d and C_l

(a) MIRA fastback model

(b) Front splitter

Figure 12

Velocity distribution along the longitudinal symmetry plane.

(a) MIRA fastback model bottom view

(b) Model with front splitter bottom view

(c) Model with front splitter

Figure 13

Pressure contours

Figure 14

Velocity distribution for canards at longitudinal plane 105 mm from centre

Figure 15

Pressure contours on canards model

Figure 16

Vortex generators 0.03608078

0 0.050 0.100 0.150 0.200 (m)

Figure 17

Pressure contours of model with vortex generator (bottom view)