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Computational Fluid Dynamic (CFD) Analysis to Determine Canard's Downforce

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Abstract

Automotive racing is universally attributed for fast lap time at high speed in a stable car. One of the engineering fits in making this to be possible is via the incorporation of canards at the frontal section of the car which increases the downforce. Such integration of an anti-lift components has omitted the need for electronic intervention. Based on physics, the downforce generated by a canard is directly proportional to its surface area, yet, at the expense of drag force increment. This is of course not desirable since drag force hinders for high speed of travelling. The objective of this study was to determine the downforce generated by two (2) identically designed canards though with varied surface areas via computational fluid dynamic (CFD) analysis for the Alfa Romeo 156. The comparison was made with respect to the surface area versus downforce generated. The CAD model for the canard was developed via Inventor software. Based on the literature, the canards were position at 30-degree angle of attack which is the optimal angle for a canard to function. The results showed that the canard which was 0.38% smaller has successfully generated 21.1% higher downforce and 26.76% less coefficient of lift at 100m/s in comparison to the relatively larger Design 2. Conclusively, a canard could be designed with minimal surface area, thus, with less drag; yet, still managed to provide significant downforce for added stability. For future study, the design used in this study could be used as the benchmark for further improvements.

Keywords

Automotive, Aerodynamics, Downforce, Canard, CFD Analysis

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Introduction

Automotive racing is indeed a very popular sport globally (Ma'arof et al. 2018). Automotive racing requires the fastest lap time in a stable vehicle (Nor et al. 2019). In any given automotive competitions, aerodynamics plays a fundamental role in achieving vehicular stability (Ruia et al. 2015; Ma'arof et al., 2018; Ma'arof et al. 2019). One of the methods commonly utilized to improve the stability of the race car is to avoid potential lift upon travelling at high speed. This is basically achieved by increasing the downforce of the race car via the incorporation of clever aerodynamics components – namely the canard. This downforce will facilitate in ensuring the vehicle to have sufficient traction without having the need for any electronic traction control system/electronic intervention. For canard, this is mainly for the frontal section of the car. A canard can generate downforce by redirect the oncoming air upwards, which generate downforce on the canard. Hence, it is a simple and straightforward integration which bares great result.

Based on physics, the downforce generated by a canard is directly proportional to its surface area, yet, at the expense of drag force increment. This is of course not desirable since drag force hinders for high speed travelling. The motivation of this study was to explore the possibility of designing a canard with minimal surface area, yet, generating equal or greater downforce as its larger counterparts. The objective of this study was to determine the downforce generated by two (2) identically designed canards but with varied surface areas via computational fluid dynamic (CFD) analysis for the Alfa Romeo 156. The comparison was made with respect to the surface area versus downforce generated.

Literature Review

A canard or otherwise known as dive plates, are miniature wings which are joined at the front bumper of a vehicle for streamlining purposes (Toet W,2013). These canards function to divert the approaching high pressure of air upwards, hence, producing downforce. The canard needs to be positioned correctly in order to prevent low pressure air from flowing on the canard which will reduce the efficiency of the canard to produce downforce. Downforce or much more accurately noted as negative lift; is indeed favourable in any automotive racings over drag (Katz et al. 2006). The drag force is undesired since it will affect the performance of the race car by means of hindering the vehicle from travelling at high speed. It should be noted that drag force cannot be eliminated, though, can be reduced and/or minimized.

In automotive aerodynamics, the drag force influences the moving of air and opposes the direction of the vehicle. There are two (2) different types of drag force, which are: (i) surface drag and, (ii) form drag. The surface drag depends on the surface of a vehicle which is in motion. The surface drag is viscous friction between the surface of the vehicle and air, determined from external shear stress. Form drag which is also known as pressure drag, is dependent on the shape or cross section of the vehicle moving in the direction against air. The surface drag force impacts the performance of a vehicle acceleration to top speed and increases the vehicle fuel economy (Hassan et al. 2014). Hence, for automotive racing, drag force is one of the main factors that need to be taken into serious considerations in order to win.

In short, there is a need to determine the balance or the optimal point where significant downforce or negative lift could be achieved or generated, whilst, monitoring the surface area of the canard in order to minimize drag. As noted, it is expected that a canard with a bigger surface area will generate a greater downforce, yet, with the adverse effects of drag force increment. Therefore, this study focused on to explore the possibility that a canard does not necessarily need to have a large surface area in order to be effectively functioning.

Research Methodology

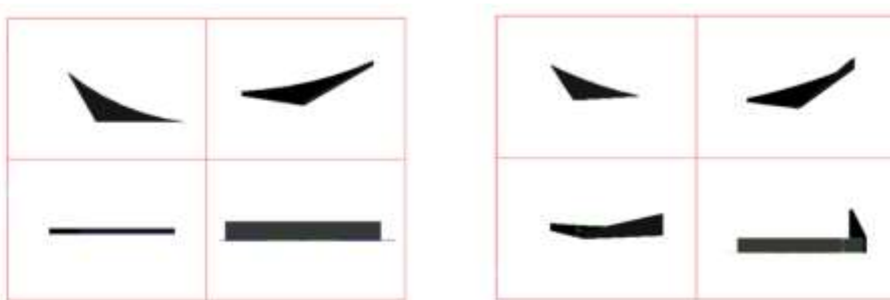
The list of variables in the assessment is shown in Table 1. Table 2 shows surface area for Design 1 and 2 Canards. Downforce of vehicle can be calculated via the following formula (Katz 1985):

$$D = \frac{1}{2}\rho A C_L v^2 \qquad (1)$$

Where, D : Downforce
ρ : Air Density, kg/m^3
A : Surface Area, m^2
C_L : Coefficient of lift
v : Velocity, m/s

Table 1 List of variables in the assessment

Controlled variable	**Independent variable**	**Dependent variable**
Velocity	Design of canard	Downforce
Angle of canard	Area	Coefficient of lift
		Coefficient of drag
		Pressure



(a) (b)

Figure 1. Canard Design* (a) Design 1, and (b) Design 2
*Note: the full measurement for the canards is confidential

Table 2 Surface Area for Design 1 and 2 Canards

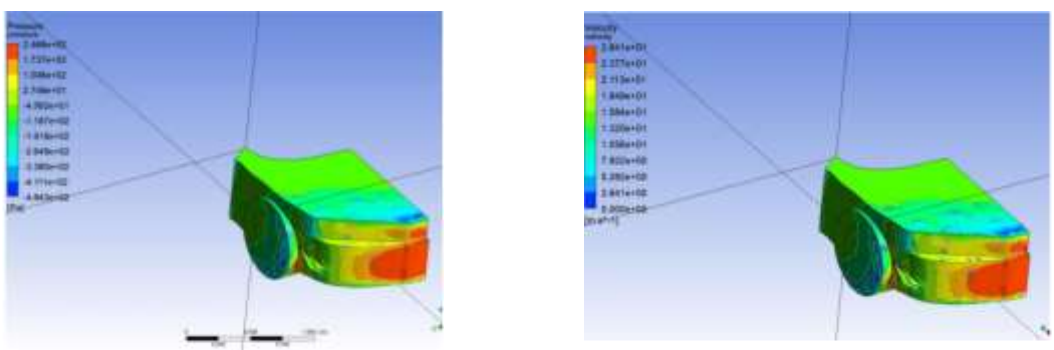
Canard	Design 1 Area (m^2)	Design 2 Area (m^2)
LH top	0.0157	0.0216
LH bottom	0.0253	0.031
RH top	0.0157	0.0216
RH bottom	0.0253	0.031

Frontal area	7.9723	7.98

The design of the canard is an inverted aerofoil. The aspect ratio is varied from 2 to 10. The taper ratio is varied from 0 to 1 and the sweep angle is varied from - 15' to +45' (Guy et al., 2000). The design is validated using ANSYS simulation fluid flow fluent. The simulation will indicate the coefficient of lift, coefficient of drag and downforce generated. The simulation used to determine down force generated by the canards is ANSYS software. The ANSYS program used is fluid flow fluent. The design of the canard was drawn using AUTOCAD and then imported to ANSYS geometry. Once the geometry has been uploaded the design modular was launched. In design modular an enclosure was used to implicate the car with canard is being tested in a wind tunnel test and a Boolean is used to subtract the car from the air.

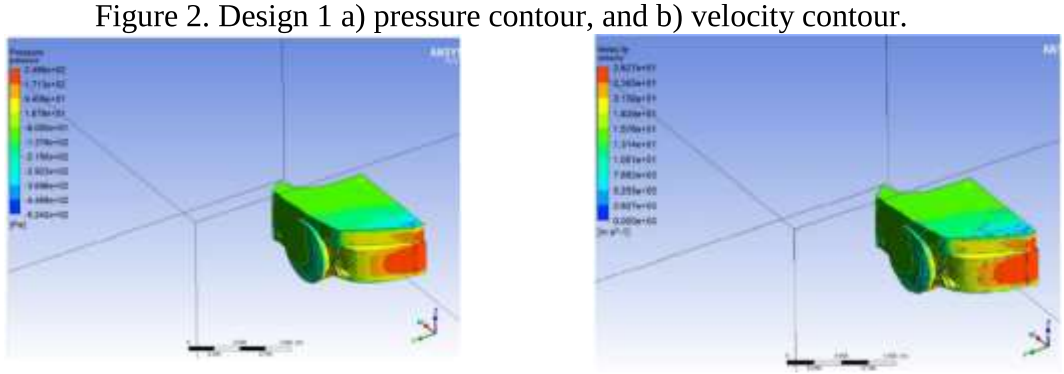
Results and Discussion

Figures 2 and 3 illustrate clearly the pressure and velocity contours for both Design 1 and Design 2 respectively. As noted, the canards were designed in an inverted aerofoil shape. By using an inverted aerofoil design for the canard, anti-lift is achieved. The working principle of an inverted aerofoil is the reversed of a generic aerofoil. For an inverted aerofoil, the upper region of the aerofoil would have a higher pressure in comparison to its lower region. Thus, creating negative lift which is known as downforce.



(a) (b)

Figure 2. Design 1 a) pressure contour, and b) velocity contour.



(a) (b)

Figure 3. Design 2 a) pressure contour, and b) velocity contour.

Table 3 Calculated result for Design 1

Velocity (m/s)	Coefficient of Drag	Coefficient of Lift	Force (N)
20	0.684	-0.437	-926.798
40	0.683	-0.438	-3,715.677
60	0.681	-0.439	-8,379.36
80	0.68	-0.435	-14,760.907
100	0.678	-0.431	-22,851.836

Table 4 Calculated result for Design 2

Velocity (m/s)	Coefficient of Drag	Coefficient of Lift	Force (N)
20	0.642	-0.361	-749.003
40	0.636	-0.362	-3,004.31
60	0.633	-0.364	-6,759.698
80	0.63	-0.368	-12,017.242
100	0.628	-0.34	-18,776.94

Tables 3 and 4 show the result obtained from the ANSYS simulation. The velocity for each simulation was kept at 20 m/s, 40, m/s, 60 m/s ,80 m/s and 100 m/s. The simulation was based on the frontal section of Alfa Romeo 156 which is drawn 1:1 to the real car. The canard is position at 30-degree angle which is the optimum angle of attack for a canard to be placed (Guy et al., 2000). The simulation was done in replicating a wind tunnel test for the determination of coefficient of lift and coefficient of drag. In this simulation, the canard was placed inside an enclosure and air is supplied from the inlet. The percentage differences which are calculated shows that the surface area of Design 1 is 0.38% smaller than Design 2, therefore, expectedly, Design 2 will result in greater downforce since it has a large surface area. Even so, the results showed that Design 1 has successfully generated a 21.1% higher downforce and 26.76% less coefficient of lift at 100m/s in comparison to the relatively larger Design 2, though, 7.9% increment in coefficient of drag. Hence, this indicated that the downforce generated by Design 1 is higher, although, the surface area is smaller. Thus, this study provides the quantitative evidences that significant downforce and low coefficient of lift could be achieved by a small and accurately designed canard. Such criteria of canard are beneficial in facilitating stability via downforce and low lift, whilst, at the same time improving the aerodynamics properties of the vehicle via low drag. Subsequently, the coefficient of drag was a fraction higher, this could be overcome via improving the shape of the canard, since it is already proven that the surface area is not the main factor for its effectiveness and functionality.

Conclusion

This paper investigates canard's downforce via CFD analysis. Conclusively, the results clearly showed that a canard does not necessarily need to have a large surface area to be effectively functioning. the canard which was $0.01m^2$ smaller Design 1 has successfully generated a 21.1% higher downforce and 26.76% less coefficient of lift at 100m/s in comparison to the relatively larger Design 2. Therefore, this study has proven that a canard does not necessarily need to have a large surface area to be effectively functioning. For future research, the optimal shape for canard could be further investigated since the coefficient of drag was just a fraction higher.

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