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AERODYNAMICS OF VEHICLE ADD-ONS

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ABSTRACT

Over 80% of the required total vehicle power is essential to overcome the aerodynamic drag and the remaining power is used for rolling resistance. An aerodynamically streamlined shape significantly reduces the aerodynamic drag thus lowering the fuel consumption. Although aerodynamics of road vehicles has been well studied, scant studies on aerodynamic effects of vehicle add-ons were reported to the public domain. Due to the life style demands, most modern passenger cars use various add-ons including roof-rack ski-rack, bicycle rack, advertising signboard, police and ambulance siren, and portable ladder. The aerodynamic impact on fuel consumption was not well studied, fully understood and quantified. Therefore, the primary objectives of this study were to experimentally measure the aerodynamic drag generated by the use of various vehicle add-ons under a range of vehicle operating speeds and cross winds conditions. The study was conducted using a reduced scale (25%) detailed model of a production large family size passenger car manufactured in Australia. The aerodynamic drag coefficient was related to fuel consumption and a detailed analysis of fuel consumption was conducted.

Keywords: Vehicle Aerodynamics, Wind Tunnel, Drag Coefficient, Vehicle Add-ons.

1. INTRODUCTION

Since the inception of the modern motor vehicle in early 1900's, vehicle manufacturers have shown little interest to streamline vehicle body shape for better aerodynamic efficiency as their priority was to make stylish cars. The oil crisis due to Middle East oil embargo in 1970s compelled vehicle manufacturers first brought sound aerodynamic design to the forefront for practical and scientific uses rather than for aesthetic purposes as in previous decades. A study by Snyder [8] indicated that in the US, if it was possible to reduce fuel consumption by as little as 1% (which typically equates to merely 0.1L/100km for a standard car) then US$30 million could be saved, which given today's car numbers could only have dramatically increased. Additionally, the economic benefit of fuel consumption reduction is also an equally important environmental upside. The world's oil resources are not infinite. As of 2009, the world burnt over 1.3 trillion litres of petrol and diesel each year for powering hundred of millions cars and trucks. If this is coupled with un-sustainable depletion and the high levels of pollution (namely CO_2) generated by burning petrol it becomes overwhelmingly apparent as to why reducing fuel consumption, if only by a small percentage, is so important to the world we live.

The primary objective of this study is to investigate the aerodynamic effects of vehicles add-ons and their impact on fuel consumption. Therefore, the primary focus will be on vehicle aerodynamic drag that is generated by various add-ons such as antenna, roof-rack, taxi sign, ladder and spoiler. A motor vehicle travelling at a constant velocity on a level road, the power required to overcome the aerodynamic drag (approximately 80%) and tyre rolling resistance (around 20%). However, with an increase of speeds, the required power increases significantly to overcome aerodynamic resistance (drag) while power required for rolling resistance remain almost constant.

$$Power_{\mathrm{Required}} = \frac{D \times S}{t} = D \times \frac{S}{t} = D \times V = \left(C_D \tfrac{1}{2} \rho V^2 \times A\right) \times V = C_D \tfrac{1}{2} \rho A V^3$$

The aerodynamic effects on current designs of vehicle add-ons spoilers, roof racks, taxi signs and ladders were not well studied and documented. Although the primary focuses of vehicle manufacturers and researchers have been concentrated on fuel saving devices of the commercial vehicles till to date [2, 3-7]. As the number of passenger cars have been increased significantly worldwide, it is utmost important to study the effects of passenger car's various add-ons on fuel cost as well as environmental impact.

2. EXPERIMENTAL PROCEDURE

2.1 Description of Vehicle Add-Ons

In order to keep the airflow around the test vehicle as practical as possible, a 25% scale model of a family size passenger production vehicle was used. The model is a true replica of a General Motors Holden VT Commodore family size passenger vehicle (see Figure 1). Various vehicle add-ons such as antenna, taxi sign, roof-racks, roof-racks with ladder attached were designed, manufactured and attached with the base car. These add-ons were 25% scale of their full size to match the scale model. Figures 1-5 show the base vehicle with various add-ons.

Fig 1. 25% Scale Model of GMH Commodore Vehicle (test vehicle) in the test section of RMIT Industrial Wind Tunnel

Fig 2. A taxi sign on the roof top of the test vehicle

Fig 3. Roof-racks on the roof top of the test vehicle

Fig 4. A ladder attached to the Roof-racks of the test vehicle

Fig 5. An antenna attached to the rare of the test vehicle

2.2 Experimental Set Up

In order to measure the aerodynamic properties of the test vehicle and vehicle add-ons experimentally, the RMIT Industrial Wind Tunnel was used. The tunnel is a closed return circuit with a maximum speed of approximately 150 km/h. The test vehicle was mounted on a six component force sensor type (type JR-3) in the test section (see Figure 1). All three forces (drag, lift and side force) and their corresponding moments were measured. The vehicle was tested alone first and then tested with each set of add-ons. A plan view of RMIT Industrial Wind Tunnel is shown in Figure 6. More details about the tunnel can be found in Alam et al. [1]. Tests were conducted at a range of wind speeds (60 km/h to 120 km/h with an increment of 10 km/h) under three yaw angles (0º, 10º and 20º yaw angles) to simulate the crosswind effects. Yaw angle can be defined as the angle between the vehicle centreline and the mean direction of airflow experienced by the vehicle.

3. RESULTS AND DISCUSSION

The percentage of aerodynamic drag increases due to antenna, taxi sign, roof rack and roof rack with a ladder over the base vehicle drag as shown in Tables 1-3 for three yaw angles (eg, 0º, 10º and 20º) respectively. As expected, the antenna has minimum aerodynamic drag increase (an average of 3% at 0º yaw angle, 4% at 10º and 20º yaw angles). The yaw angles have virtually no effect on the antenna due to its circular shape. The taxi sign has increased aerodynamic drag an average of 11% at 0º and 10º yaw angles and 9% at 20º yaw angle (see Tables 1-3). A 2% reduction of aerodynamic drag at 20º yaw angle was noted compared to other two yaw angles due to the oblique angle of taxi sign to the wind direction thereby lowered the projected frontal area of the taxi sign. Similar effect was also noted for the roof rack. However, the roof rack with a ladder had significant impact on aerodynamic drag. As shown in Tables 1-3, an average 12%, 14% and 17% aerodynamic drag increase over the base vehicle were noted at 0º, 10º and 20º yaw angles respectively. With an increase of yaw angles, the roof rack with a ladder generated more drag as its projected frontal area increased. Additionally, the airflow around the roof rack with a ladder became more complex and chaotic with yaw angle increase.

For a passenger car with an annual travelling distance of 25,000 km with an average speed of 60 km/h, estimated fuel consumption, fuel cost and the amount of CO_2 due to vehicle add-ons (antenna, taxi sign, roof rack and roof rack with a ladder) are shown in Tables 4-6. The tables clearly indicates that with an increase of yaw angles, the aerodynamic drag, fuel consumption, cost and greenhouse gas (CO_2) emission increases. The roof rack with a ladder and the bare roof rack have more impact on aerodynamic drag, fuel consumption and environment than the antenna and taxi sign.

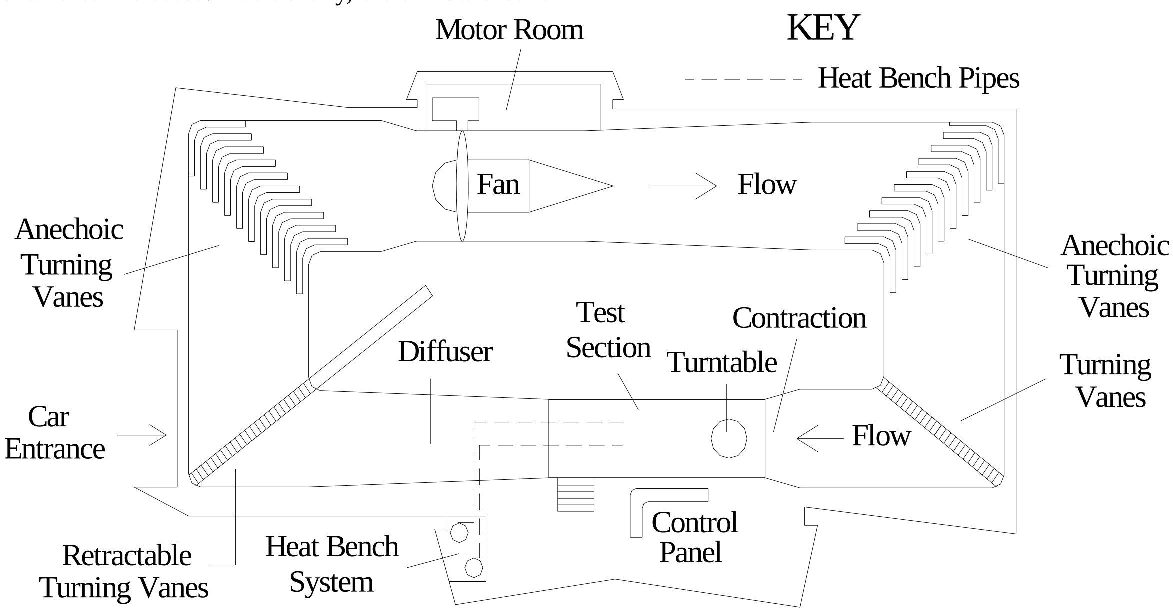

Table 1: Drag increase over base vehicle in percentage for 0º yaw angle

Speed	Antenna	Taxi sign	Roof rack	Roof rack w/ladder
km/h	%	%	%	%
60	5.57	11.49	5.48	13.14
70	3.61	9.28	7.30	11.30
80	2.73	10.64	7.88	10.71
90	2.46	10.59	7.82	13.60
100	3.99	11.22	6.52	12.17
110	2.31	13.77	5.49	11.17
120	3.82	11.89	6.42	12.59
Average	3	11	7	12

Table 2: Drag increase over base vehicle in percentage for 10º yaw angle

Speed	Antenna	Taxi sign	Roof rack	Roof rack w/ladder
km/h	%	%	%	%
60	2.08	10.34	8.40	13.06
70	3.62	7.91	6.70	13.87
80	4.89	9.44	5.95	13.71
90	4.24	8.57	6.04	10.18
100	3.01	13.27	10.41	9.47
110	5.50	13.04	11.25	16.62
120	5.42	12.97	8.09	17.83
Average	4	11	8	14

Table 3: Drag increase over base vehicle in percentage for 20º yaw angle

Speed	Antenna	Taxi sign	Roof rack	Roof rack w/ladder
km/h	%	%	%	%
60	-1.63	12.73	3.58	9.64
70	-3.77	11.36	5.42	15.44
80	5.77	6.08	3.69	21.95
90	4.36	6.27	7.17	17.62
100	7.19	7.53	4.72	18.07
110	7.85	8.17	5.37	17.66
120	6.61	7.95	6.67	17.90
Average	4	9	5	17

Table 4: Fuel cost and CO_2 emission at 0º yaw angle

Average milage 25000 km/year for 60 km/h average speed at 0 deg yaw angle					
	Base	Antenna	Taxi	Roof rack	Roof rack w/ladder
drag (N)	102	105	113	109	114
Fuel (L)	241	249	268	258	270
Cost @$1.2/L ($)	290	298	322	310	325
CO_2 (kg)	596	614	662	638	668

Table 5: Fuel cost and CO_2 emission at 10º yaw angle

Average milage 25000 km/year for 60 km/h average speed at 10 deg yaw angle					
	Base	Antenna	Taxi	Roof rack	Roof rack w/ladder
drag (N)	119	124	132	129	136
Fuel (L)	282	293	313	304	321
Cost @$1.2/L ($)	338	352	375	365	385
CO_2 (kg)	696	724	772	752	793

Table 6: Fuel cost and CO_2 emission at 20º yaw angle

Average milage 25000 km/year for 60 km/h average speed at 20 deg yaw angle					
	Base	Antenna	Taxi	Roof rack	Roof rack w/ladder
drag (N)	136	141	148	143	159
Fuel (L)	322	335	351	338	377
Cost @$1.2/L ($)	386	402	421	406	452
CO_2 (kg)	795	827	867	835	930

4. CONCLUSIONS

The following concluding remarks have been made based on the experimental study presented here:

- The vehicle add-ons have notable impact on aerodynamic drag as they can generate 5 to 20% more aerodynamic drag depending on yaw angles.
- The antenna has minimum impact and the roof rack with a ladder has highest impact on aerodynamic drag. The roof rack with a ladder generates higher drag compared to antenna and taxi sign.
- The average fuel consumption considerably increases due to vehicle add-ons, especially due to rook rack and roof rack with ladders.
- The removal of vehicle add-ons can not only save fuel consumption but also reduce significant amount of greenhouse gas emission.

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7. NOMENCLATURE

Symbol	Meaning	Unit
D	Drag Force	(N)
L	Lift Force	(N)
S	Side Force	(N)
C_D	Drag Coefficient	-
C_L	Lift Coefficient	-
C_S	Lateral-Force Coefficient	-
Re	Reynolds Number	-
V	Velocity of Air	m/s
ρ	Density of Air	kg/m^3
A	Projected Area	m^2
S	Distance Travelled by vehicle	m

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