

Aerodynamic Performance of Road Vehicles

M. A. Murtaza



Abstract: Aerodynamic drag has been experimentally estimated for scale models of a passenger car and a commercial truck in a wind tunnel. Polished surface has resulted up to 15 % reduction in drag force and add-on has resulted in 57% increase in drag force of a car model whereas 2.6 % reduction in drag force has resulted by using deflector in a commercial truck model. Anova analysis shows variation in mean of group data.

Keywords: Scale Model, Passenger Car, freight truck, Wind Tunnel, Aerodynamic Drag, Drag coefficient, Anova.

I. INTRODUCTION

A fuel-efficient vehicle not only saves fuel but also the environment. Reduction in fuel consumption is obtained by improved engine efficiency, reduction in weight and aerodynamic drag reduction. Apart from development of new technologies of electric vehicles and fuel cells, reduction in energy consumption such as electronic devices in various road vehicle systems has taken place. It is also reducing environment and noise pollutions.

An object interacts with outside world; a scale model [1] is its physical representation. Such studies on a scale model help in improving the object. This approach has been followed in automobile industry. Scale models have been used for aerodynamics and interior noise analysis.

II. LITERATURE REVIEW

Harun et al [2] conducted wind tunnel tests on a 1/10 scale model of a semi-trailer truck to assess fuel saving devices in the context of aerodynamics. Fairing and covering, frontal fairing, side skirting and gap filling were used as external attachments and obtained 26% reduction in aerodynamic drag.

Firoz et al [3] experimentally measured the aerodynamic drag generated at various vehicles operating speed.

For this purpose, the study was conducted using a reduced scale detailed model of a passenger car.

The aerodynamic effects of vehicle add-ons and their impact on fuel consumption were investigated.

The vehicle add-ons not only increase the fuel consumption and greenhouse gas emission but also significantly deteriorate the directional stability, thus impacting the safety of vehicle.

Uendra et al [4], [5] studied the effect of rear screen and rear fairing, two passive devices. Tests were conducted on a small-scale model of General Motor SUV. Use of rear screen could result reduction in drag up to 6.5% and 26% reduction was obtained by use of fairings.

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III. METHODOLOGY

A wooden passenger car scale model [7] and a commercial trailer truck model [8] were used for aerodynamic drag analysis experimentally in wind tunnel.

In order to measure the aerodynamic drag force experimentally, a road vehicle model was kept on the stand of the wind tunnel and fastened to measure drag force.

Velocity of air was measured using a pitot tube and inclined U-tube manometer and velocity is computed by following relation.

$$V_{\text{air}} = \sqrt{2g * \Delta h * \sin \theta}$$

The pressure head difference Δh is for the inclined manometer. Inclination angle of manometer was 30.2 deg. To measure drag force, WH-A series portable digital electronic scale was used. The drag coefficient [6] is obtained by the following equation.

$$C_d = \frac{2F}{\rho v^2 A}$$

Where F is the drag force, ρ is the mass density of air, v is the speed of the object relative to air and A is the reference /projected area (which is 0.012 sq. m. for passenger car model and becomes 0.015 after putting a wooden block on the car model as an add-on). Rolling friction of car model was 0.170kg

The range of air velocity for these tests were from 84.88 to 97.65 kmph for car model and 61.8 to 94.8 kmph for trailer truck model.

A. Passenger car model:

Tests were conducted for the following cases.

- Unpolished car model, A = 0.012 sq. m.
- Polished car model, A = 0.012 sq. m.
- Car model with add-on, A = 0.015 sq. m.



Fig. 1: Experiment with Car Model

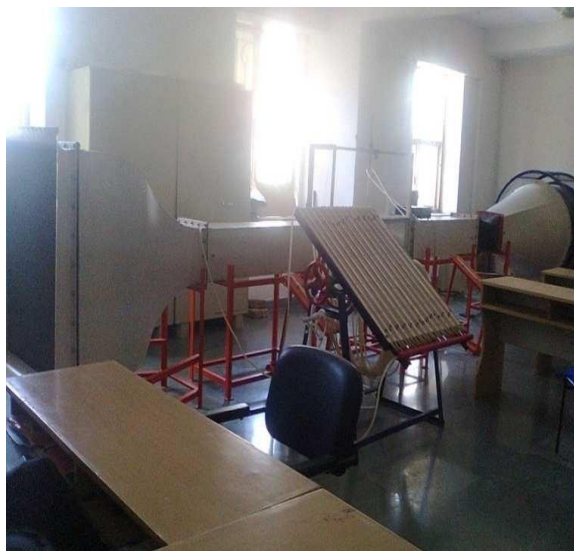


Figure 2: Wind Tunnel Set Up

B. Commercial Vehicle:

Wooden truck model as shown in fig. 3 was used with and without deflector for conducting tests in wind tunnel, $A = 0.006$ sq.m.

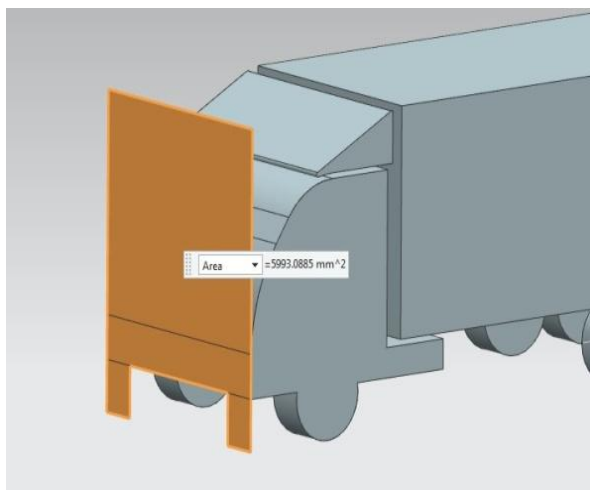


Fig. 3 projected area of truck model

Table 1: Tests on a car model on various experimental conditions.

Car Model	V kmph	A m sq	Drag force N	Drag coefficient Cd
Before polish	97.65	0.012	7.286	1.361584
	92.07	0.012	6.119	1.312851
	84.88	0.012	4.551	1.103646
with polish	97.65	0.012	7.108	1.270109
	92.07	0.012	3.941	0.916912
	84.88	0.012	3.571	0.809341
With add-on	97.65	0.015	10.382	1.593146
	92.07	0.015	9.46	1.625435
	84.88	0.015	6.511	1.373426

Table 1 gives data of car model under different conditions viz. Unpolished, polished and with add-on during wind tunnel tests.

Table 2: Wind tunnel test results on truck model

MODEL	Wind velocity (km/hr)	Drag force (N)	Drag coefficient (C_D)
Without deflector	61.8	8.8	0.83
	84.2	14.7	0.75
	94.8	19.1	0.76
With deflector	59.5	6.8	0.7
	77.5	12.7	0.76
	96.3	18.6	0.72

Wind tunnel test results of trailer truck with and without deflector are given in table-2.

IV. RESULT AND DISCUSSION

(i) Car model without polish:

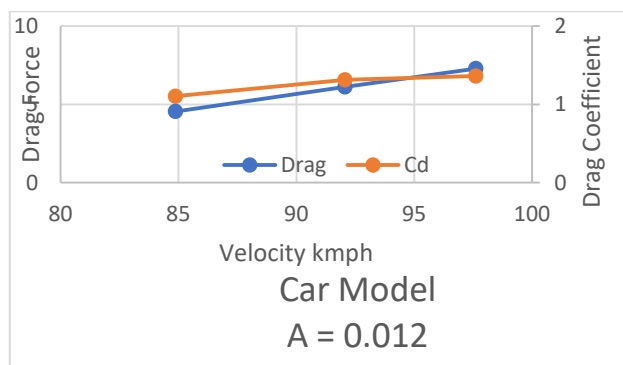


Fig. 4: Drag force and drag coefficient vs velocity of car model without polish

Fig. 4, shows the variation of drag force and drag coefficient with velocity when the wooden model was without polish. Drag force increases from 4.53 to 7.35 N when the air velocity increases from 84.88 kmph to 97.65 kmph. Drag coefficient increases from 1.1 to 1.36 as stream velocity increases from 84.88 to 97.65 kmph.

(ii) Car model (Polished):

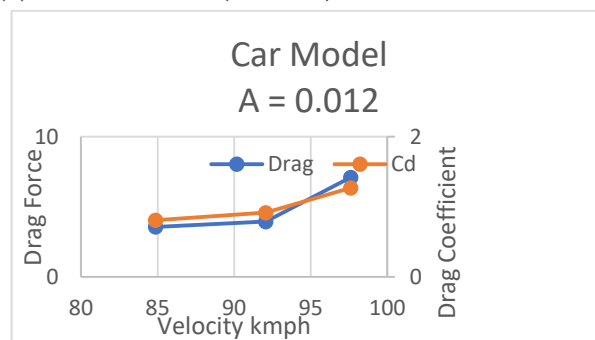


Fig. 5: Variation of Drag Force and drag coefficient with Velocity (Polished).

Fig. 5, shows the variation of drag force with velocity in case of the car model when its surface was polished. Drag force in this case varies from 3.2 to 7.26 N for the same velocity range. It is evident that there is a reduction in drag force with polished surface.

This reduction is 15.3 % at 84.88 km/hr and 1.22% at 97.65km/hr. Drag coefficient increase from 0.8 to 1.27 as velocity increases for the same velocity range. There is 27 % reduction at 84.88 kmph and 6% reduction at 97.65 kmph.

(iii) Car model (Polished) with add-on

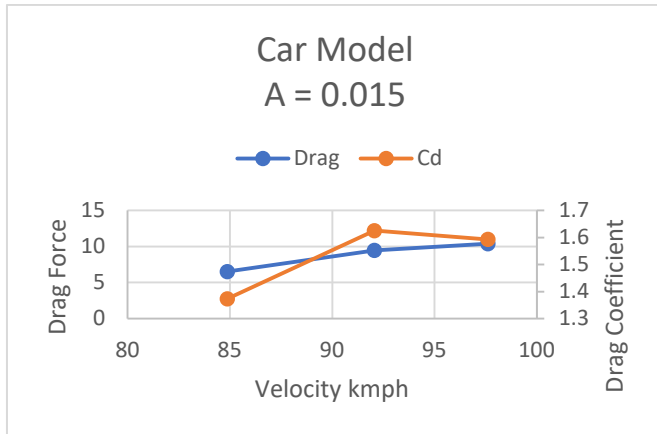


Fig. 6: Drag Force and drag coefficient vs Velocity in Case of Car Model with Add-on

Fig. 6, shows the results with a loaded polished model. Add-on on roof of car model has resulted in increase in projected area from 0.012 m² to 0.015 m². Drag force varies from 7 kg to 10.6 kg in the same velocity range. There is 57% increase in drag force. The drag coefficient increases from 1.28 to 1.61. Because of this load, there is an increase in drag coefficient is of the order of 52% at 84.88 kmph and 26.7% at 97.65 kmph.

(iv) Truck model without deflector.

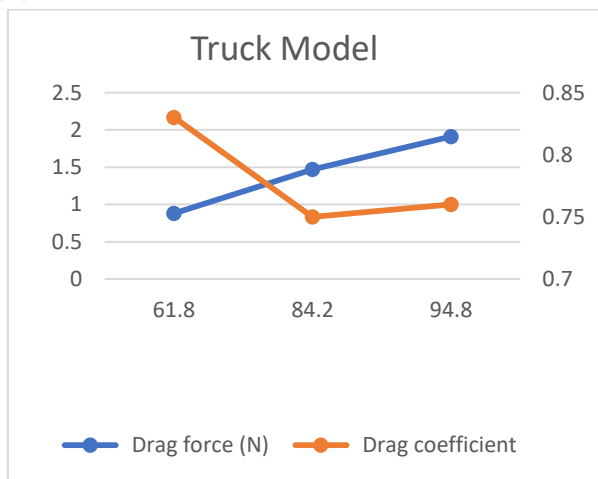


Fig. 7 Drag force x 10 and drag coefficient with wind velocity (without deflector)

Fig. 7, shows the variation of drag force and drag coefficient in case of a truck model without wind deflector. Drag force increases from 8.8 N to 19.1 N when velocity of wind increases from 61.8 km/hr to 94.8 km/hr. The drag coefficient first decreases and then increases. It decreases from 0.83 to 0.76 when wind velocity increases from 61.8 km/hr to 94.8 km/hr.

(v) Truck model with deflector

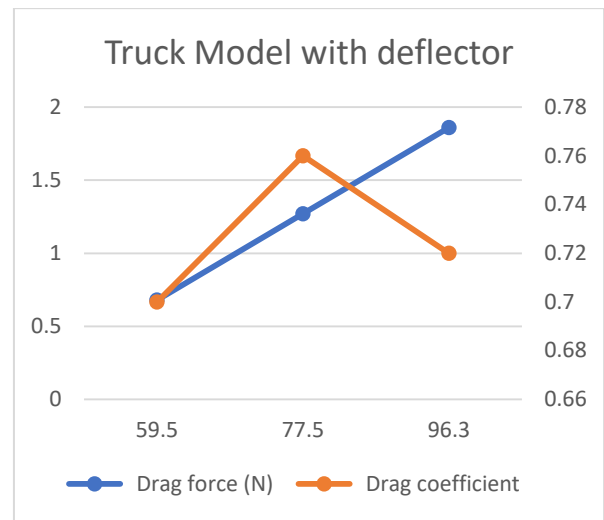


Fig. 8. Drag force x 10 and Drag coefficient Vs wind velocity (with deflector).

As shown in Fig. 8, drag force varies from 6.8 N to 18.6 N when wind velocity increases from 59.5 km/hr to 96.3 km/hr. It is clear from the above result that there is reduction in drag force when wind deflector is used. It decreases from 19.1 N to 18.6 N at 96.3 kmph.

The drag coefficient increases when velocity increases from 59.5 km/hr to 75 km/hr. After speed of 75 km/hr, the drag coefficient decreases to 0.72.

V. ANOVA ANALYSIS

Statistical (Anova: single factor) analysis of data of table 1 & 2 was done on Excel, details are as following.

(a) Passenger Car Model:

SUMMARY						
Groups	Count	Sum	Average	Variance		
Column 1	12	110.399	9.199917	128.02		
Column 2	12	100.123	8.343583	115.7962		
Column 3	12	88.6676	7.388967	99.18978		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	19.69656	2	9.848279	0.086135	0.917676	3.284918
Within Groups	3773.067	33	114.3354			
Total	3792.763	35				

(b) Commercial truck model

SUMMARY						
Groups	Count	Sum	Average	Variance		
Column 1	8	50. 822	6. 35275	52. 76793		
Column 2	8	73. 822	9. 22775	101. 0063		
Column 3	8	92. 272	11. 534	150. 9189		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	Fcrit
Between Groups	107. 8127	2	53. 90635	0.53076	0. 595841	3. 4668
Within Groups	2132. 852	21		101.5644		
Total	2240. 664	23				

In both these analysis p-value was more than $\alpha = .05$, therefore null hypothesis fails and mean value variation in groups exists.

VI. CONCLUSIONS

A scale model of a passenger car without polish, with polish and with an add-on on the roof and a commercial truck model with and without deflector were used for wind tunnel tests. Conclusions from these tests are as following. Anova analysis of mean of groups shows variation in data collected.

1. Reduction in drag force due to improvement in surface finish were 2.44%, 35% and 21% on speeds 97.65, 92.07 and 84.88 kmph respectively and increase in drag force due to add-on on car model was 46%, 140% and 82% on these test speed.

2. On commercial trailer truck model with deflector, the reduction in drag force was 22.7%, 13.6% and 2.6% respectively on the test speeds used for trials.

3. The increase due to add-on is substantial and similarly reduction due to surface finish on car model and use of deflector on the truck model are appreciable there is a need to further extend the study by using CFD approaches for automobile design optimisation.

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