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Academic @ Paper
ISSN 2146-9067

International Journal of Automotive
Engineering and Technologies

Vol. 4, Issue 4, pp. 185 – 192, 2015

International Journal of Automotive
Engineering and Technologies

http://www.academicpaper.org/index.php/IJAET

Original Research Article

The Passive Flow Control Around a Truck-Trailer Model

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Received 22 July 2015 Accepted 22 November 2015

Abstract

In this study the aerodynamic characteristics of 1/32 scale truck and trailer model were examined in a wind tunnel. The acting drag force to model truck and trailer combination is calculated and aerodynamic drag coefficient is determined. The wind tunnel tests were carried out in the range of 159 000 - 453 000 Reynolds numbers. In order to improve the aerodynamics structure of truck- trailer, one spoiler, one passive air channel and three different redirector is produced in three dimensional printer. These aerodynamic parts respectively added to base truck-trailer model and obtaining aerodynamic improvement rates compared. According to wind tunnel test results, the aerodynamic improvement rates are respectively 14.78%, 18.06%, 23.15%and 20.70%. The lowest drag coefficient was determined as 0,584on model-3 of truck-trailer model.

Keywords: The aerodynamic drag coefficient, passive air channel, passive flow control, wind tunnel

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1. Introduction

The different resistance forces affect to vehicles during the movement. These are aerodynamic resistance, transmission, slope, rolling and acceleration resistances. One of the forces acting on the vehicle is aerodynamic drag force. Aerodynamic drag force becomes important at higher speed sand vehicle performance and fuel consumption are significantly influenced. Because the aerodynamic drag force increases proportional to the square of the speed.

The heavy vehicles perform cruising at high speed in intercity and take way too much over the years. The vehicle manufacturers invest aerodynamic studies in order to increase vehicle performance.

It is seen on the shape in Fig. 1 shape that forming aerodynamic drag regions on heavy vehicles. A large amount of drag based on pressure drag is consisted on the front surface, the wheels, the gap between the truck and trailer and the rear of the trailer [1].

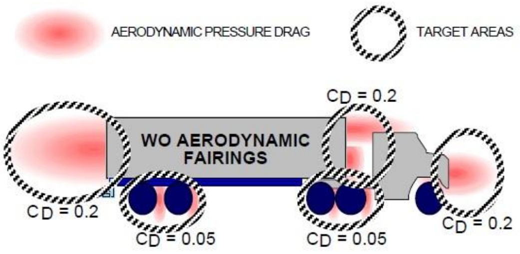

Fig. 1The high pressure drag regions on heavy vehicles [1]

The aerodynamics resistance force significantly affect the vehicle’s performance, fuel consumption, acceleration properties, handling characteristics, environmental pollution, noise and comfort. Moreover, the cooling system of engine and the heating interior ventilation system have a direct relationship with the aerodynamics. Aerodynamic drag coefficient is increased proportionally with the square of the speed. This status makes the improving aerodynamics drag more important issue for heavy vehicles which perform a large part of the transportation out of the city and a lot of mile sat high speeds for a year. [2]. A passenger car with 100 km speed an hour spends 60% of its power to afford the forces of drag [3].

The passive and active flow control methods are used to improve the aerodynamics of the car. Perzon, and Davidson [4] provided the aerodynamic improvements with three different models. By rounding the back of the trailer he achieved 4 %, with nose cone 3% and with chassis skirt% 7 aerodynamic improvement is obtained [4].With increasing windshield attack angle drag coefficient decreases on a commercial vehicles [5].

Modi et al. [6] aerodynamic improvement is obtained on 1/6 scale a truck and trailer model. The vertical and horizontal spoiler put at the front of the trailer have achieved to improve by 12.5% and 28% respectively. A large part of the aerodynamic drag is formed on the front surface area of truck. Gilieron and Kourta [7] achieved 12% aerodynamic improvement using redirector plate. Fouree et al. [8] obtained 9% lower drag coefficient using flow deflector on a generic car model depending different deflector angle. Beaudoin and Aider [9] made the wind tunnel tests on a Ahmed body model. They used flaps at all the edges on the two rear surfaces. Depending on various type flaps the drag coefficient reduced by 25%.

According to Ogburn and Ramroth, a decrease of 20 % in drag force is obtainable by adding some aerodynamic part on truck and trailer. The improvement in that ratio decrease fuel consumption about 10 % at or over 105 km / h speed [10].

In this study, a 1/32 scaled model vehicle was used. Although it is a licensed model and the similarity errors are assumed to be negligible, the results of base model may not correspond that of the real vehicle.

The aim of the study is to show the effect of passive control methods used on a truck-trail model. After determination of drag coefficient for a base model, decreasing of the drag coefficient is intended by using some passive flow control parts. The effects of using aerodynamically designed spoiler is determined to C_D coefficients and fuel consumption.

2. Material Methods
2.1 Experimental setup

The size of suction type wind tunnel test region is 570 mm x 570 mm x 1000 mm. The rpm of the fan motor was been controlled to achieve the desired free stream velocity in the test region by using frequency inverter. The frequency inverter operates in the range of 0-50Hzand has 0.1 Hz step, to control 4 kW powered axial fan of 700 mm diameter. The minimum and maximum free stream velocity in the range of 0-20 m/s. Turbulence intensity is below 0.7% in the wind tunnel. The wind tunnel tests were carried out in the range of 113 000 - 449 000 Reynolds numbers. The blockage ratio is 3.06 %. The view of wind tunnel and model vehicle are given in Fig. 2 and Fig.3.

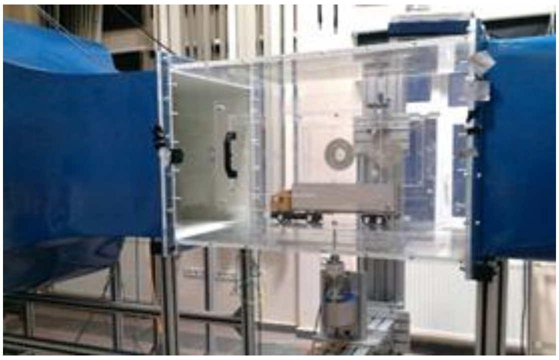

Fig. 2.General view of wind tunnel

Fig. 3. 1/32 Scaled model vehicle

2.2. Passive flow control

A specific flow structure is dominant around the object in the flow. The change of this flow to out of common is called flow control. Depending on the energy consuming, there are two method so flow control as passive and active flow control. On the contrary of active flow control, there is no energy expenditure in the passive flow control. Generally, the passive flow control is carried out changes the form of the geometry that examining aerodynamic shape of the body.

2.3. Description of Model

1/32 scaled truck trailer model is used in the experimental studies. It is a licensed model of a truck trailer brand. The features of model truck trailer model are given in Table 1.

Table 1.The Features of Model Vehicle

Body and Chassis: Die cast metal,
Bumper, Mirrors, Trailer and Glass: Plastic
Sizes of Truck-Trailer: Height: 13.3cmWidth: 8.3cm,Length (L): 47.1cm
Characteristics Area of Truck-Trailer (A) : 99,35cm²

2.4. The Force Measurements

Aerodynamic drag coefficient is expressed with the parameters of drag force F_D, the density of air ρ, the free stream velocity V and as the front projection area of vehicle A.

$$\boldsymbol{C_D} = \frac{\boldsymbol{F_D}}{\frac{1}{2}\boldsymbol{\rho V^2 A}} \qquad (1)$$

The measurement of drag forces was carried out a six-axis load cell which is ATI brand Gamma model. Load cell can measure Fx and Fy forces up to ±32 N and Fz force up to±100N. It can measure Mx, My, Mz moments in the range of ± 2.5Nm.

The force measurements were made at 8 different Reynolds numbers. In the experiments, the data were taken at 400Hz with averaging at 100Hz during 40s. Four sample were recorded in a second and 160 samples were obtained from each measurement. The drag coefficient has been calculated by averaging of these samples.

2.5. Establishing Of Similarities Rules for Study

The experimental studies related to vehicle aerodynamics on real prototypes are quite expensive and difficult. So, scaled model vehicles can be used in the wind tunnel experiments. Three different similarities are required between prototypes.

2.5.1. Geometric Similarity

To ensure geometric similarity, the sizes of model should be proportional to that of the prototype. In the wind tunnel tests 1/32 scaled model vehicle is used.

2.5.2. Kinematic Similarity

The ratios of the velocity vector on prototypes and models should be same to provide kinematic similarity [11].Providing kinematic similarity also depends on blocking effect in the wind tunnel experiments. Blockage ratio is defined as projection area of the front surface of the model, proportional to area of the front surface of wind tunnel test section.

In the literature, blockage ratio is recommended to be below the 7.5 % limit for the blocking effect to be neglected in wind tunnel tests [11].

In this study, blocking ratio is 3.06%. As this value is in accordance with the criteria given in the literature, the effects of blockage have been neglected. On the other hand, the relative velocity between the vehicle and the floor has not been considered by using a moving surface. The test model placed on a flat plate, which is 8 cm over the tunnel bottom surface, to obtain uniform velocity profile for the approaching real flow.

2.5.3. Dynamic Similarity

Reynolds number is defined as the ratio of inertial forces to viscous forces.

$$Re = U_\infty \, L/v \qquad (2)$$

Reynolds number must be the same for model and prototype in the studies where inertia and viscous forces are effective force to ensure full dynamic similarity. However, unless models and prototypes aren’t in the same size, it is very difficult to achieve equality in the numbers of Reynolds. Dimensionless coefficients above a certain speed value may not affected by the Reynolds number.

Due to the Reynolds number independence the dynamic similarity can be assumed as provided for the flow over bluff bodies like trucks and buildings. The drag coefficient may not change after a threshold value of Reynolds number. In the case of the boundary layer and the wake are fully turbulent [12, 14 and 15].

2.5. Uncertainty Analysis

In this study the results of the uncertainty analysis of the calculated parameters are taken from Bayındırlı [2] PhD thesis studies. Because all wind tunnel tests made with same test devices and flow conditions. Uncertainty value for the Re number were obtained as 3.87%.by writing ρ, U_{Pitot}, H and µ argument of uncertainty values. The uncertainty values of drag forces were obtained as 4.5%. It was calculated for Re = 312 000 value. The uncertainty value for the aerodynamic force coefficient were obtained as 4.7% by writing F, ρ, A, argument of uncertainty values. The Uncertainty value for the pressure coefficient (C_P) were obtained as 2.11 %.by writing ΔP, ρ and U argument of uncertainty values.

3. Result and Discussion

3.1. The drag force measurements of base model

As a result of the experiments is given Table 3.1. The average drag coefficient (C_D) of base model truck and trailer was determined as 0.77.

Table 3.1. The drag coefficient (C_D) values of base model

Reynolds Number	C_D
159 000	0,75
202 000	0,78
239 000	0,79
282 000	0,74
323 000	0,76
364 000	0,75
406 000	0,76
449 000	0,75

The experiments were made in eight different speed and average aerodynamic drag coefficient (C_D) is calculated as 0.76. This result is compatible the literature (13).

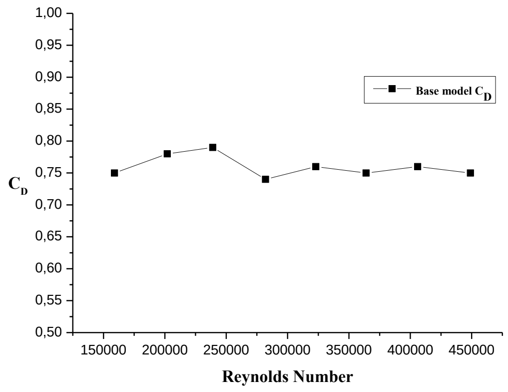

Fig.4. The drag coefficient graph of base model

3.1.1. The aerodynamic improvements with spoiler (Model 1)

A spoiler is manufactured with 30° inclination angle to provide aerodynamic improvement. The spoiler is compatible designed with the dimensions of a truck and trailer dimensions on SolidWorks®programme. The new designed spoiler is given in Fig. 5.

Fig. 5. Model 1 truck and trailer

The spoiler was producted by three dimensional printer. Three dimensional printer and producted spoiler are given Fig 6, and Fig 7.

Fig .6. Three dimensional printer

Fig. 7. The new designed spoiler

By new designed spoiler in Fig. 8, the air which is affecting upper front region of trailer is transferred to upper part of the trailer and pressure based drag force is reduced. So, the aerodynamic improvement of14,78 % is obtained by new designed spoiler.

3.1.2. The aerodynamic improvements with spoiler, passive air channel and redirector 1 (Model 2)

On conventional trailer models, the air flow separates after a while which is transferred onto the trailer by spoiler. This flow separation create negative pressure area and increases the drag force. In this study, the air separation is prevented and air flow stream is passed through a channel. The air flow was maintained at the trailer upper surface and transferred rear of the trailer and with redirector.

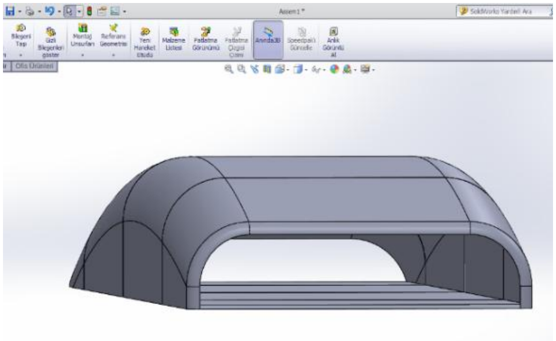

Fig. 9. The drawing data of passive air channel

Three different redirectors were produced to obtain the best results. These redirectors respectively added to passive air channel and test results compared.

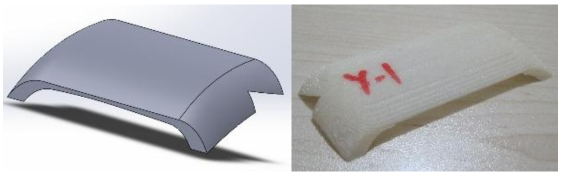

Fig. 10. Redirector 1

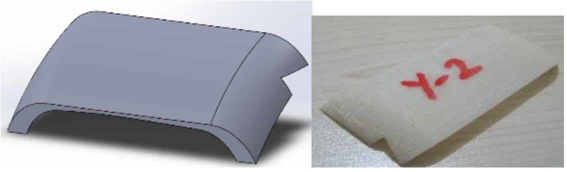

Fig. 11. Redirector 2

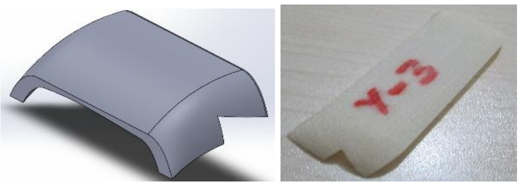

Fig. 12. Redirector 3

The large negative pressure in the rear part of the trailer forms a significant amount of aerodynamic drag on truck and trailer combinations.

In this model, it was targeted that create a smaller negative pressure region in the rear part of the trailer. Model 2 truck-trailer, mounted passive air channel and redirector 1are given in the Fig.13.

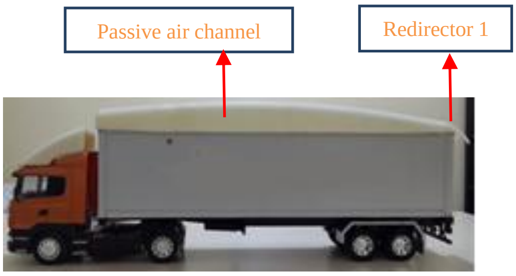

Fig. 13. Model 2 truck and trailer

As seen in the Table 3.4, the average aerodynamic drag coefficient (C_D) is calculated as 0.623formodel 2. This coefficient value is lower than the cases of the base model and the model 1.

Table 3.4. The measured force and C_D values of Model 2

Reynolds Number	C_D
160 000	0,62
203 000	0,6
240 000	0,62
283 000	0,59
326 000	0,6
368 000	0,6
410 000	0,6
453 000	0,59

The obtained aerodynamic improvement is 18.06% by new designed spoiler, passive air channel and redirector 1 (model 2). Obtained aerodynamic improvement between the model 1 and model 2 is3.17% for passive air channel and redirector1.

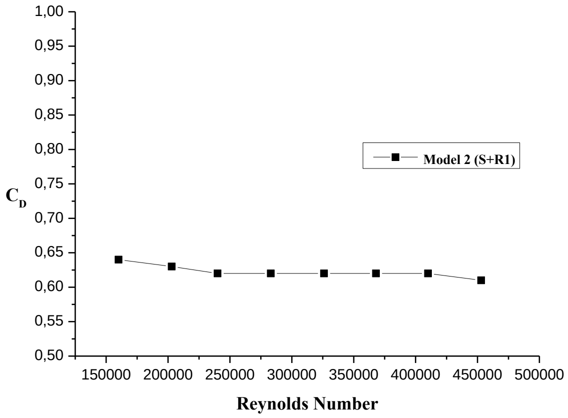

Fig.14. The drag coefficient graph of model 2

3.1.3. The aerodynamic improvements with spoiler, passive air channel and redirector 2 (Model 3)

As seen in the Table 3.3, the average aerodynamic drag coefficient (C_D) is calculated as 0.584 for model 2. This coefficient value is lower than that of the base model, model 1 and model 2.

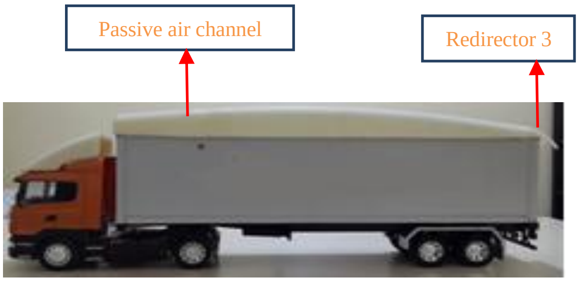

Fig. 15. Model 3 truck and trailer

Table 3.3. The drag coefficient (C_D) values of Model 3

Reynolds Number	C_D
160 000	0,61
203 000	0,59
240 000	0,58
283 000	0,6
326 000	0,57
368 000	0,58
410 000	0,57
453 000	0,57

23.15% aerodynamic improvement is obtained by new designed spoiler passive air channel and redirector 2 (model 3). According to model 1, the aerodynamic improvement was8.37% for passive air channel and redirector 2. The lowest drag coefficient value is obtained in this model.

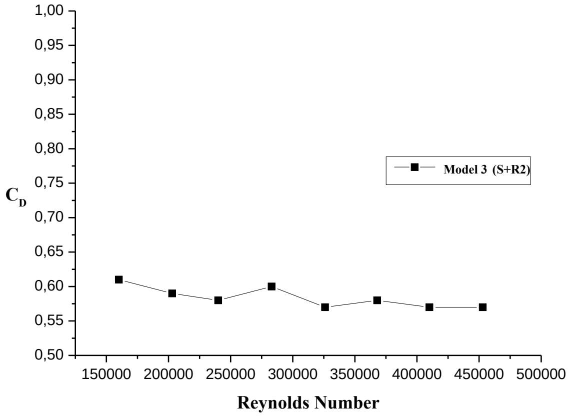

Fig.14. The drag coefficient graph of model 3

3.1.4. The aerodynamic improvements with spoiler, passive air channel and redirector 3 (Model 4)

The experiments were made in eight different speed and average aerodynamic drag coefficient (C_D) is calculated as 0.603.The results for the model 4, truck and trailer which is seen in Table 3.4 and Fig 17.

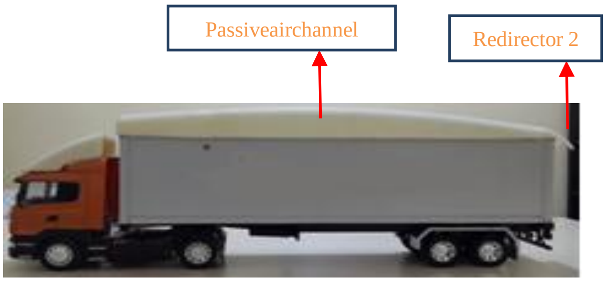

Fig. 16. Model 4 truck and trailer

Table 3.4. The drag coefficient (C_D) values of Model 4

Reynolds Number	**C_D**
160 000	0,62
203 000	0,6
240 000	0,62
283 000	0,59
326 000	0,6
368 000	0,6
410 000	0,6
453 000	0,59

20.70% aerodynamic improvement is obtained at the model 4. This value is lower than base model, model 1 and model 2, but higher than model 3.

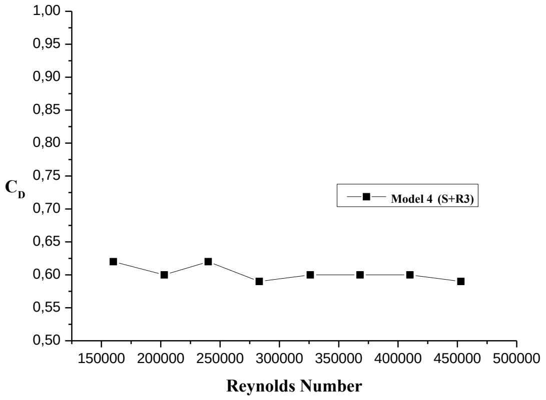

Fig.17. The drag coefficient graph of model 4

4. Conclusion and Recommendations

In this study, the drag force values acting on the truck trailer combination were determined experimentally in a wind tunnel. The experimental studies are made at Reynolds numbers in the range of160 000-449 000.

A summary of the results of experiments are presented below.

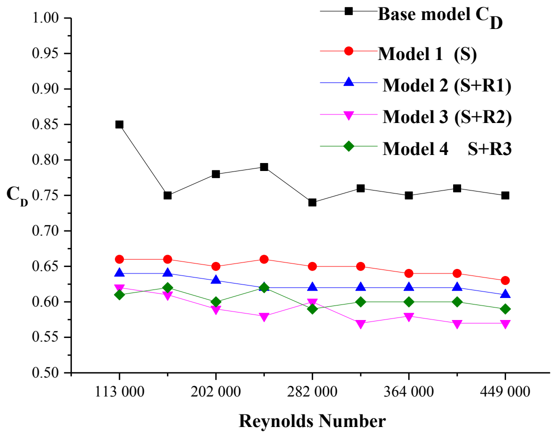

Fig. 18. The drag coefficient comparison graph of model 1, model 2, model 3, model 4 and base model

- ✓ The geometric shape of the spoiler should be designed more curved and inclination angle should be narrow in order to reduce aerodynamic drag.
- ✓ In this study 14.78% aerodynamic improvement rate was obtained by then designed spoiler (Model 1). At this aerodynamic improvement ratio can reduce fuel consumption by about 7.5 % at high speeds.
- ✓ 18.06% aerodynamic improvement rate was obtained by new designed spoiler,

passive air channel and redirector 1 (model 2).

- ✓ After the wind tunnel tests, the lowest C_D coefficient is obtained as 0,584 on model 3. 23.15 % aerodynamic improvement rate was obtained by new designed spoiler, passive air channel and redirector 2 (model 3). According to literature [1, 2, 6, 8 and 9] this aerodynamic improvement ratio can reduce fuel consumption by about 12 % at up of the 90 km/h.
- ✓ 20.70% aerodynamic improvement rate was obtained at the model 4.
- ✓ It is recommended that three passive flow method applicable at the same time to improve of the aerodynamics structures of the truck trailer combinations.

Acknowledgement

The authors would like to acknowledge the financial support of this work by the Scientific Research Projects Unit (BAP) of Nigde University with the contract number of FEB 2013/12.

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