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Original Research Article

The Experimental Investigation of the Effects of Spoiler Design on Aerodynamic Drag Coefficient on Truck Trailer Combinations

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Abstract

In this study, surface pressure and drag force measurement was measured at 6 different free flow velocities on a heavy vehicle model, consisting of truck and trailer, placed in the wind tunnel. The aerodynamic drag coefficient was determinate for three different models which are unspoiled model, the standard spoiler and new design spoilers model. As a result of wind tunnel tests, the effects of spoiler design on the aerodynamic drag coefficient was defined. The experimental studies were performed on 156000- 844000 Reynolds number. In experimental studies, kinematic similarity was provided and blocking effects were neglected. In the dynamic similarity condition, the independence of Reynolds number was used. The pressure coefficient distributions on the vehicle were determined with the experiments of pressure measurement. The pressure coefficient was found to be high at the top of the trailer which is higher than truck and on the front bumper. % 11.37 the aerodynamic improvement was obtained by new spoiler design according to the model 2 with standard spoiler.

Key Words: The aerodynamic drag coefficient, wind tunnel, truck trailer combination, spoiler design

Note:
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1. Introduction

One of the forces acting on the vehicle is aerodynamic resistance force. Aerodynamic drag force becomes important at higher speeds and vehicle performance and fuel consumption are significantly influenced. Because the aerodynamic drag force is increasing proportional to the square of the speed. That's why a large part of looking outside the city, especially at high speeds and perform many more miles per year for the aerodynamic resistance of the vehicle that heavy vehicles are the most important considerations to make. The heavy vehicles perform to cruising at intercity with high speeds and take way too much over the years. The vehicle manufacturers are investing to aerodynamic studies in order to increase of vehicle performance.

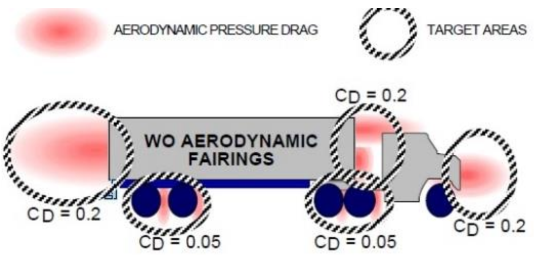

Figure 1. The high pressure resistance regions on heavy vehicles [1]

The aerodynamics resistance force significantly affects 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 miles at 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 vehicle [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 an 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]. The aerodynamic characteristics of 1/32 scale truck and trailer model were examined in a wind tunnel. In order to improve the aerodynamics structure of truck- trailer, one spoiler, one passive air channel and three different redirectors is used. The aerodynamic improvements are obtained respectively 14.78 %, 18.06 %, 23.15 % and 2.70 % [16].

The aim of this study is to examine the aerodynamics structures of truck and trailer combinations experimentally. To view and investigate the flow around the truck and trailer by flow visualization methods. After determination of drag coefficient for a base model, decreasing of the drag coefficient is intended by using new designed spoiler.

2. Experımental Setup

The size of suction type wind tunnel test region is 400mm x 400mm x 1000mm. The rpm of the fan motor was been controlled to achieve the desired free stream in the test region by using frequency inverter. The frequency inverter operates in the range of 0-50 Hz and has 0.1 Hz step, to control 4 kW powered axial fan of 700 mm diameter. A six-component load cell has been used to measure Fx and Fy forces up to ± 32N and Fz force up to ± 100N. It can measure Mx, My, Mz moments in the range of ± 2.5Nm. Turbulence intensity is below 1% in the wind tunnel. The wind tunnel tests were carried out in the range of 156 000 - 844 000 Reynolds numbers. The minimum and maximum free velocity in the range of 0-28 m/s. The blocking rate is 8.31 %. The view of the test devices and wind tunnel is given in Fig. 2.

Figure 2. General view of the test devices and wind tunnel [2]

1/32 scaled model vehicle is used in the wind tunnel tests. The features of the model car are given at the Table. 1.

Table 1. The Features of Model Vehicle [2]

Body and Chassis	Diecast metal
Bumper, Mirrors, Trailer and Glass	Plastic
Appearance	Metallic Blue, Grey Painted, Smooth
Sizes of Truck-Trailer Height	16.17 cm Width: 9.2 cm, Length (L): 48.878 cm
Characteristics Area of Truck-Trailer (A)	0,0132 m^2
Characteristics Area of Truck (A)	0,0108 m^2

2.1. The providing conditions of similarity rules for wind tunnel tests

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

2.1.1. Kinematic similarity

The ratios of the velocity vector on prototypes and models should be fixed for providing kinematic similarity [11]. The providing of kinematic similarity also depends on the blocking effect in the wind tunnel tests. Blocking rate is defined as the ratio of front surface area of model vehicle to the chamber cross-sectional area. Providing kinematic similarity also depends on blocking effect in wind tunnel experiments. Blockage rate is defined as sectional area of the front surface of the model proportional to sectional area of the front surface of wind tunnel test chamber. In the literature, blockage ratio is recommended to be below the 10% limit for the blocking effect to be neglected in wind tunnel tests [3]. In this study, blocking rate is 8.31% and agreement with the literature [11]. As this value is in accordance with the criteria given in the literature, the effects of blockade have been ignored while experimental data are being assessed.

2.1.2. 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. It is a licensed model and the error has been neglected depends on the surface roughness. The image of prototype vehicle and 1/32 scaled model car are given in the Fig.3 and Fig.4.

2.1.3. Dynamic similarity

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

$$Re = U_\infty L/v \tag{1}$$

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 are not affected by the Reynolds number. If this coefficient does not change as Reynolds number increases, it means that dynamic similarity is provided. In this study, Reynolds number independence was obtained in all of the experimental work. In Fig. 5, Reynolds number independence was obtained in wind tunnel tests.

Figure 3. Prototype Vehicle

Figure 4. Model Car

2.2. The tests of pressure measurement

A total of 32 taps were located symmetry axis of the vehicle, 13 taps of which on the truck and 19 taps of which on the trailers, have been used. The tests of truck trailer combination were carried out in the range of 156 000 – 844 000 Reynolds number. Dynamic pressure which was used obtained from the pressure taps on the inlet and outlet of the wind tunnel contraction cone. Two differential type pressure converter is used in the pressure measurements. It is Omega PX163-2.5BD5V model, the output voltage of 0-5 volts detection time is 1 millisecond. Before the pressure measurements, the calibration of pressure transducers is made. The determining of surface pressure, 800 data is received in a second, this value is below of the detection time capacity of the pressure transducer (1000 Hz). Total of 16 384 data has been taken and each measurement taken is 20.48 seconds.

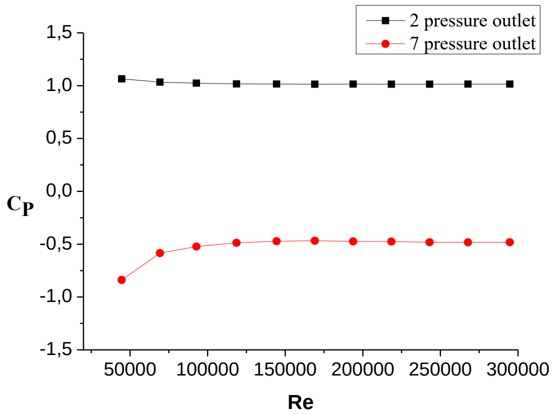

Figure 5. Reynolds independent in tests

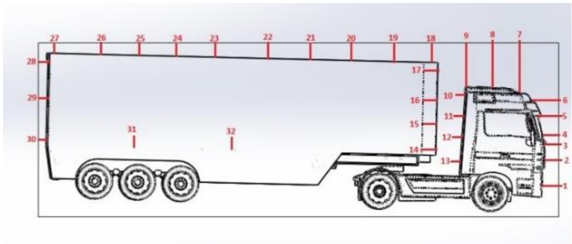

Figure 6. The location of the pressure probe on model car [2]

The difference between total pressure and static pressure gives the dynamic pressure.

$$P_{dyn} = P_{total} - P_{st} \tag{2}$$

$$P_{dyn} = \frac{1}{2}\rho V^2 \tag{3}$$

$$C_P = \frac{\Delta P}{\frac{1}{2}\rho V^2 A} \tag{4}$$

In the experimental studies, atmospheric pressure, dynamic pressure, free stream velocity and ambient temperature were measured with a Manoair 500 model digital micro manometer.

2.3. The force measurement tests

The 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.

$$C_D = \frac{F_D}{\frac{1}{2}\rho V^2 A} \quad (5)$$

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 ± 32N and Fz force up to ± 100N. It can measure Mx, My, Mz moments in the range of ± 2.5Nm. The force measurements were made 6 different speeds (5 m/s, 10 m/s, 15 m/s, 20 m/s, 25 m/s, 27 m/s). During the one minute two results have been taken per second. The drag coefficient has been calculated based on a total of 120 results.

2.4. Uncertainty analysis

In this study the results of the uncertainty analysis of the calculated parameters are given below.

2.4.1. Calculation of the uncertainty value of the Reynolds number

Uncertainty value for the Re number were obtained as 1.3%.by writing ρ, U_{Pitot}, H and μ argument of uncertainty values instead of equation 7.

$$u_{Re} = \frac{w_{Re}}{Re} = \left[\left(u_\rho\right)^2 + \left(u_{Pitot}\right)^2 + (u_H)^2 + \left(u_\mu\right)^2\right]^{1/2} \quad (7)$$

2.4.2. Calculation of the uncertainty value of the drag force

The uncertainty values that is acting coefficient of drag forces was obtained as 4.5%. It was calculated for U = 10 m / s and Re = 312 000 value.

$$\frac{w_{F_D}}{F_D} = \left[\left(\frac{w_{X_1}}{X_1}\right)^2 + \left(\frac{w_{X_2}}{X_2}\right)^2 + \left(\frac{w_{X_3}}{X_3}\right)^2 + \left(\frac{w_{X_4}}{X_4}\right)\left(\frac{w_{X_4}}{X_4}\right) + \left(\frac{w_{X_5}}{X_5}\right)^2\right]^{1/2} \quad (8)$$

2.4.3. Calculation of the uncertainty value of the aerodynamic drag coefficient

The uncertainty value for the aerodynamic force coefficient were obtained as 4.7%.by writing F, ρ, A, argument of uncertainty values instead of equation 9.

$$u_{C_D} = \frac{w_{C_D}}{C_D} = \left[\left(u_{F_D}\right)^2 + \left(u_\rho\right)^2 + 4\left(u_{pitot}\right)^2 + \left(u_{A_{ön}}\right)^2\right]^{1/2} \quad (9)$$

2.4.4. Calculation of the uncertainty value of the pressure coefficient (C_P)

The Uncertainty value for the pressure coefficient (C_P) were obtained as 2.11 %.by writing ΔP, ρ and U argument of uncertainty values instead of equation 10.

$$u_{C_P} = \frac{w_{C_P}}{C_P} = \left[\left(u_{\Delta P}\right)^2 + \left(u_\rho\right)^2 + 4\left(u_{pitot}\right)^2\right]^{1/2} \quad (10)$$

3. Result and Discussion

3.1. Pressure coefficient (c_P) distribution on base model (model 2)

As seen at Fig. 7, the pressure coefficient has been found high on the 17,18 and 19 probes due to the fact that trailer is higher than the of truck. The separated flow over spoiler has reattached on the trailer where higher region than truck.
The pressure coefficient (C_P) was found to be 0.96 on the probe 18. It has been shown that this value is close to stagnation pressure (2th probe, C_P=1) that is located on the front bumper.

3.2. The Drag Force Measurements

3.2.1. Model 1 (Without spoiler)

The different type spoilers use on truck trailer combinations in order to improve drag force. Despite, many spoilers model does not provide enough improvement.

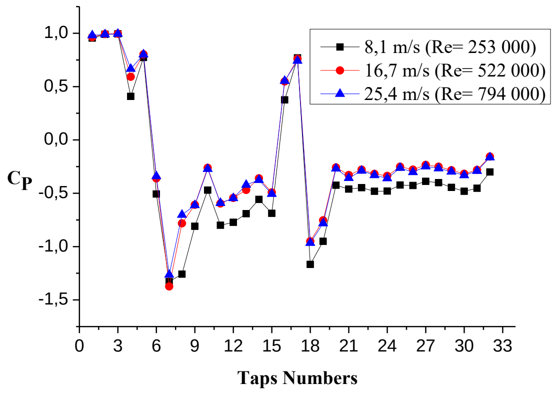

Figure 7. The pressure coefficient (C_P) distribution on the truck trailer combination [2]

When analyzing the distribution of pressure coefficient, it is seen that the drag coefficient can be decreased and new designed spoiler design. The base model truck trailer is given in Fig.8

Figure 8. The model 1 car (without spoiler)

As seen in Fig. 9, the aerodynamic drag coefficient of without truck and trailer was measured as 0.769.

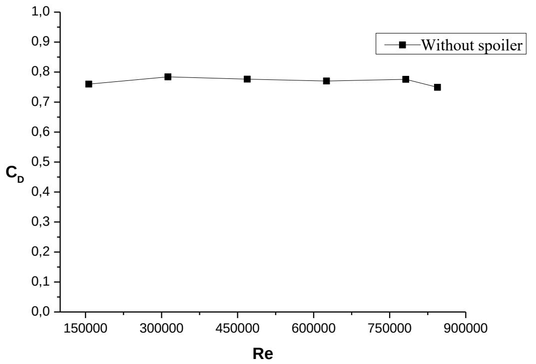

Figure 9. The drag coefficient graph of without spoiler model vehicle (model 1)

3.2.2. Model 2 (Standard spoiler)

As seen in Fig. 11. the aerodynamic drag coefficient of model 2 was measured as 0.706. After the drag force measurements, 10.33 % aerodynamic improvement was obtained according to model 1 using standard spoiler.

The flow visualization of standard spoiler model 2 is given in Fig. 12. When analyzing the flow visualization, it is seen that a flow separate is occurred on the trailer. This flow separating forms large negative pressure area rear part of trailer. Also, aerodynamic structure is negatively affected due to negative pressure region between truck and trailer.

3.2.3. Model 3 (New designed spoiler)

When the analyzed the distribution of pressure coefficient (C_P) of standard spoiler the model vehicle air acting on the front of the tractor have been shown to act directly on the region where 18 number locate the probe. Wherein it was determined that close to the stop pressure C_P coefficient. A new spoiler designed and the vehicle assembly is made to obtain an aerodynamic improvement in this area.

Figure 10. The model 2 car (standart spoiler) [2]

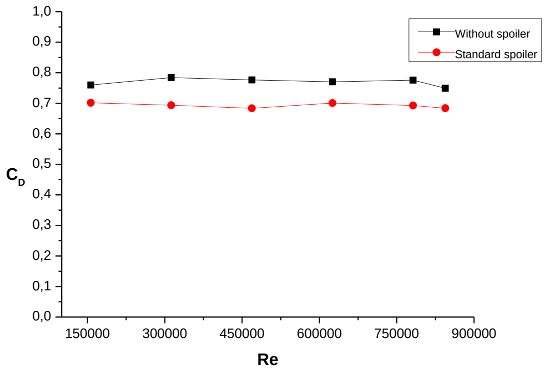

Fig.11. The drag coefficient graph of standard spoiler model (model 2)

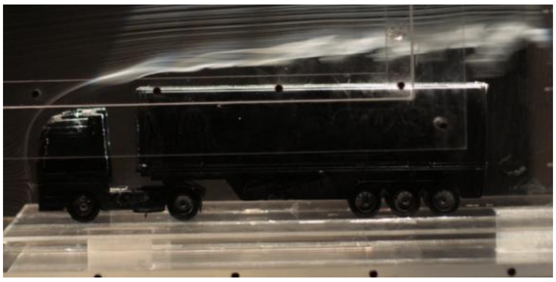

Figure 12. Flow visualization of model 2 [2]

Figure 13. The model 3 which has new designed spoiler

As seen in Fig.14, the average C_D coefficient is calculated as 0.625 for model 3. In this case, 11.37% aerodynamic improvement is obtained according to model 2 by the produced new spoiler.

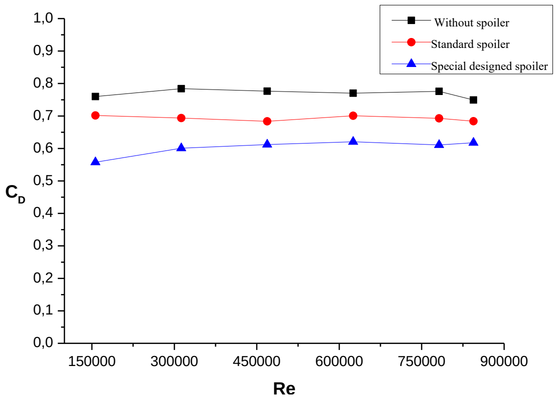

Figure 14. The drag coefficient graph of without spoiler-standard spoiler-new designed spoiler

As seen in Fig.15, using new designed spoiler, the air which is affecting upper front region of trailer (17 taps) is transferred to upper part of the trailer (18,19, 20 taps) and pressure based drag force is reduced. The flow lines more smooth than model 2.

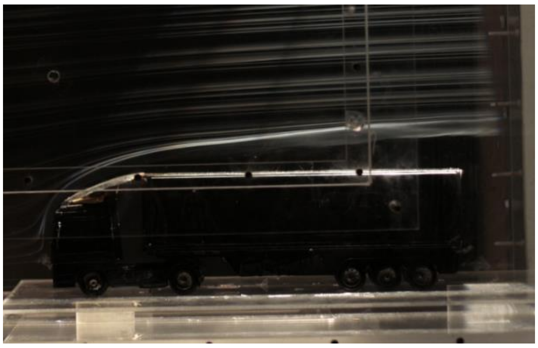

Figure 15. Flow visualization of model 3

4. Conclusions

In freight transport, heavy vehicles with trailer are used intensively. These vehicles are making long-kilometers at high speeds per year on intercity or international roads. This case makes aerodynamics structures of heavy vehicles even more important.

According to Wood and Bauer (2003) when the aerodynamic drag coefficient was reduced 2%, fuel consumption is reduced by 1% at 96 km / h speed for truck trailer combinations.

In this study 11.37% aerodynamic improvement rate was obtained by the new designed spoiler. At this aerodynamic improvement ratio can reduce fuel consumption by about 6 % at high speeds.

In Turkey, there are a lot of vehicles in freight transport in this situation. Assuming that a vehicle goes to average 100,000 kilometer way an annual and spend 25 liters for 100 kilometers. In this case, the annual fuel consumption of a vehicle is 25,000 liters.

At the model 3, 11, 37 % aerodynamic improvement is obtained by new designed spoiler. Whereby fuel consumption can be reduced by 6 %. This means that each car will consume 1 500 liters less fuel annual. Its contribution to Turkey's economy is 15 000 000 liters for 100,000 vehicles. Therefore, spoiler structure must be appropriate height. It is recommended to have narrow attack angles of spoiler.

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