The Impact of Using Trailers on the Fuel Consumption

František Synák[1], Vladimír Rievaj[1], Štefánia Semanová[1], Ján Palúch[1]

[1]Department of Road and Urban Transport, Faculty of Operation and Economics of Transport and Communications, University of Zilina, Univerzitná 1, Žilina, 010 26

Abstract The amount of fuel consumed may also be influenced by driving style, speed as well as by the need for the use of passenger car trailers. This paper deals with the impact of using such trailers on the amount of fuel consumed. Measurement of the impact of the passenger car trailer on fuel consumption was carried out during driving at constant speed and during acceleration. The measurements were performed by driving test on a flat road. The first part of the paper deals with the driving resistances which influence fuel consumption during driving at constant speed and during acceleration on the flat road. The second part describes the vehicle used for measurements and measuring equipment. The conclusion of the paper includes the principles to reduce the impact of passenger car trailers on the amount of fuel consumed.

Keywords air resistance, carbon dioxide, fuel consumption, global pollution, rolling resistance, trailer,

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1. Introduction

The total of 2.5 kg of CO2 is produced by combusting 1 l of petrol. By combusting 1 l of diesel, it is even 2.7 kg of CO2 [1]. Within the European Union, road transport produces about 20 % of carbon dioxide [2], of which about 75 % is produced by passenger cars [3]. Transport, as one of sectors with growing amount of CO2 produced, has a great potential to contribute to the emission reduction and meet the obligations arising from the Paris Agreement [4]. Not only vehicle manufacturers have the obligation to contribute to the reduction of this greenhouse gas production based on the legislation [5], but there is also a moral obligation for every driver to contribute to meeting this goal as much as possible. The requirement for compliance with eco-driving principles is also included in White Paper where Annex I states that it is necessary to include ecological way of driving into the future revisions of the driving licence directive and take steps to accelerate the deployment of ITS application in support of eco-driving [6]. The purpose of this paper is to assess one of principles of eco-driving which represents considering the use of passenger car trailers in such cases when it is possible to store transported goods in the vehicle luggage compartment. For this reason, the paper focuses on increasing fuel consumption due to attaching the passenger car trailer.

The driving resistances are increased by connecting a trailer to a towing vehicle [7]. A vehicle engine must then overcome these driving resistances [8]. Therefore, the engine must consume a certain amount of energy contained in the fuel to produce sufficient power [9]. The trailer increases air drag [10] and rolling resistance during driving at constant speed [11]. Air drag depends on driving speed, vehicle frontal area, aerodynamic drag coefficient, and air pressure [12]. It may be expressed by the following formula:

$$\mathbf{R_{aero} = 0,5 \cdot v^2 \cdot S \cdot c_x \cdot \rho} \quad (1)$$

v – driving speed [$m \cdot s^{-1}$]
S – vehicle frontal area [m^2]
c_x – aerodynamic drag coefficient [-]
ρ – air density [$kg.m^{-3}$] [13]

The rolling resistance depends on the vehicle weight which is dependent on the vehicle mass and coefficient of rolling resistance [14]. The rolling resistance may be calculated as:

$$R_f = G \cdot f \quad (2)$$

G – vehicle weight [N]
f – coefficient of rolling resistance [-] [15]

During acceleration, the trailer increases also the resistance to acceleration. The value of this resistance to accelerate is influenced by the vehicle mass, the resistance of rotating parts to acceleration, and range of acceleration or deceleration. The resistance to acceleration may be expressed in a simplified manner by the following formula:

$$R_a = m \cdot \delta \cdot a \quad (3)$$

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m – vehicle mass [kg]
δ – coefficient of the resistance of rotating parts [-]
a – acceleration [m·s⁻²] [16]

The aim of this paper is to ascertain a change in values of driving resistances due to the use of the passenger car trailer based on the measurements performed. The impact on the amount of fuel consumed is also examined.

2. Methods

The measurement of the impact of the passenger car trailer on the change in fuel consumption was carried out in two variants. The first variant represented measurements at constant speed 50 km·h-1 and 90 km·h-1. In the second variant, measurements were carried out during vehicle acceleration from zero speed to 50 km·h-1 and 90 km·h-1.

2.1. Vehicle Used for Measurements

The vehicle used for the measurements was Škoda Octavia 1. Technical specifications are given in Table 1.

Table 1 Technical parameters of the vehicle

Modification (Engine)	1.9 TDi, PD
Production year	2008
Engine power	74 kW . 4000 rpm
Torque	240 Nm 1900 rpm
Number of gears	5, manual transmission

The trailer used for the measurements was Agados and its technical specifications are given in Table 2.

Table 2 Technical parameters of the trailers

Dimensions	1250 x 2060 x 350
Kerb weight	136 kg
Total weight	500 kg
Highest allowed speed	100 km·h^{-1}
Production year	2008
Tyre	175/65 R13
Energy efficiency class of tyres	„C“, 7,8 ≤ RRC ≤ 9,0

The trailer in complete assembly is shown in Figure 1.

Figure 1 The passenger car trailer used for the measurements

The transported cargo weighed 275 kg and it is shown in Figure 2.

Figure 2. Transported cargo.

In case that the trailer was not used, cargo was placed in the vehicle luggage compartment as it is shown in Figure 3.

Figure 3. Placement of cargo in the vehicle luggage compartment

2.2. Measurement Tools

Weather station Irox HRS 70 was used to measure the air flow velocity. The air pressure was recorded at the level of 1030 hPa and air temperature was from 20°C to 21 °C.

The driving speed, amount of fuel consumed, engine speed, accelerator pedal movement and driving time were determined by using VAG V.C.D.S 15.7.1 software. A connection between VAG diagnostic software and the vehicle control unit was ensured by the use of a special HEX CAN cable. Work environment of the program is shown in Figure 4.

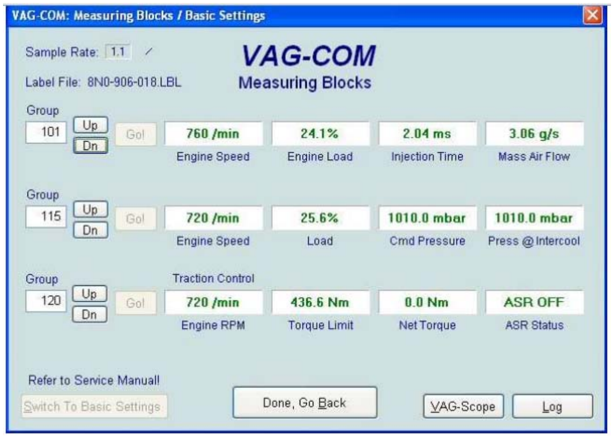

Figure 4. Work environment of program VAG V.C.D.S.

The program's output VAG V.C.D.S shows the fuel consumption in l.h-1 which is needed to be recalculated into l.100 km-1. Since the program's frequency of data writing is approximately 3times per second, the calculations were carried out via Microsoft Excel. In the first step it was necessary to recalculate the fuel consumption from l/h into l/s according to the equation:

$$Q_s = \frac{Q_h}{3600} \tag{4}$$

Qs – fuel consumption per second [l.s-1]
Qh – fuel consumption per hour [l.h-1]

The second step included the calculation to determine the amount of fuel consumed per period of time during which the fuel consumption was measured:

$$Q_c = Q_s \ .t \tag{5}$$

Q_c – amount of fuel consumed per period of measuring [l]
Q_s – fuel consumption per second [l.s^{-1}]
t – time period of measuring [s]

$Q_{l100} = \frac{Q_c}{s} \ .100\ 000$The time period of measuring is equal to the frequency of data writing, and thus it is approximately 0.33s. The fuel consumption was subsequently calculated in l.100 km-1 according to the equation:

(6)

Ql100 – fuel consumption [l.100 km-1]
s – trajectory of measuring [m]

The given calculation was carried out for each writing during the measurement, and the result of all the measurements was averaged.

2.3. Measuring the impact of using the trailer on fuel consumption during driving at constant speeds

The measurement procedure to ascertain the impact of using the trailer on fuel consumption during driving at constant speed was as follows:

1. Vehicle acceleration,
2. achieving constant speed,
3. start of recording the values,
4. driving at constant speed,
5. end of value recording and saving them.

The measurements were carried out three times at speed 50 km·h^{-1} and three times at speed 90 km·h^{-1}. Subsequently, the frame of the trailer, (indicated by number 1 in Figure 1) was removed and measurements were repeated three times separately for speed 50 km·h^{-1} and 90 km·h^{-1}. After complete removal of the plastic cover of the trailer (indicated by number 2 in Figure 1, the measurements were repeated again. In the end, the trailer was disconnected, cargo was loaded into the vehicle luggage compartment and the measurements were repeated again. During each measuring the vehicle speed was recorded. If there was a speed change by more than ± 2 km.h^{-1} from the speed at which the measurement should have been done, the measuring was annulled. To record the value went around 3 times per second.

2.4. Measuring the impact of using the trailer on fuel consumption during vehicle acceleration

The measurement procedure to determine the impact of using the trailer on fuel consumption during vehicle acceleration was as follows:

1. stopping the vehicle on a flat road
2. start of recording the values
3. vehicle acceleration to the desired speed
4. recording the values after achieving the desired speed

The measurements with the trailer were carried out three times for vehicle acceleration to the speed of 50 km·h-1 and three times to the speed of 90 km·h-1. Subsequently, the trailer was disconnected, cargo was loaded into the vehicle luggage compartment and the measurements for vehicle acceleration were repeated again three times separately for speed 50 km·h-1 and 90 km·h-1. During vehicle acceleration to the speed of 50 km·h-1, gears from 1 to 4 were employed and gears from 1 to 5 were employed to achieve 90 km·h-1. Only those measurements were taken into the results, of which the mutual correlation was lesser than 0.97. The mutual correlation of the engine and vehicle speed was taken into consideration. The application of acceleration pedal was compared only in the case of measuring under the same conditions, that means there were mutually compared only those measurements with trailer or the measurements without trailer. The repetition of accelerations with such accuracy was very difficult and only about half of the measurements conducted met this condition. For better display, the Figure 5 shows the example of comparison of how the curves of the engine speed are changing during two accelerations.

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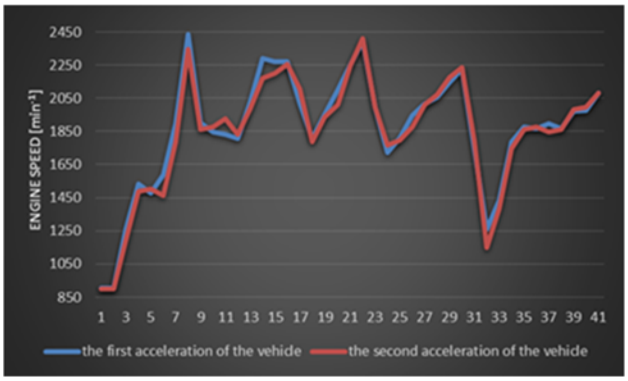

Figure 5. Comparison of the engine speed during two vehicle accelerations.

3. Results

The fuel consumption values during driving at constant speed are given in Table 3.

Table 3 Fuel consumption measured during driving at constant speed

Version	50 km·h^{-1}	90 km·h^{-1}
Fuel consumption with the trailer in complete assembly [l·100km^{-1}]	4.2	6.1
Fuel consumption in the case of the dismantled frame [l·100km^{-1}]	4.2	5.8
Fuel consumption in the case of the removed trailer plastic cover [l·100km^{-1}]	4.2	6.3
Fuel consumption in the case of cargo loaded in the trunk (without using the trailer) [l·100km^{-1}]	3.7	4.7

For greater clarity, the results are also depicted in the graph in Figure 6.

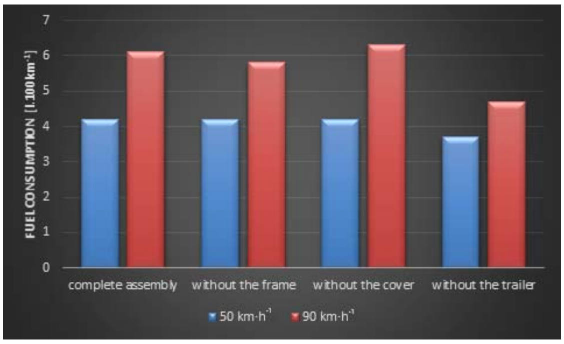

Figure 6. The values measured during driving at constant speed

As it can be seen from Table 3 and Figure 6, the removal of the frame or the plastic cover of the trailer did not affect the amount of fuel consumed in the case of driving at speed 50 km·h^{-1}. By disconnecting the trailer and loading the cargo into the luggage compartment, fuel consumption decreased by 0.5 l·100km^{-1} which represents CO_2 reduction by 1.4 kg·100 km^{-1}.

When driving without the trailer frame at speed 90 km·h^{-1}, fuel consumption decreased by 0.3 l·100 km^{-1} which resulted in CO_2 reduction by 0.84 kg·100 km^{-1}. This decrease was apparently caused by reducing the air resistance of the trailer [17]. The frame mounted on the plastic cover of the trailer disrupts the air flow around surface of the cover and this results in increasing the aerodynamic drag coefficient [18].

Removal of the plastic cover increased fuel consumption by 0.2 l·100 km^{-1}. This increase can be explained by the fact that after removing the cover the air flow entered into the space for transporting cargo and it acted the rear wall of the trailer. The inner side of the rear wall thus created another frontal area [19].

The difference in fuel consumption between driving without the trailer (with cargo loaded in the vehicle luggage compartment) and driving with the trailer in complete assembly represented 1.4 l·100 km^{-1} which resulted in CO_2 reduction by 3.92 kg·100 km^{-1}.

The fuel consumption values during the vehicle acceleration are given in Table 4.

Table 4 Fuel consumption measured during driving at constant speed

	Acceleration to 50 km·h^{-1}	Acceleration to 90 km·h^{-1}
Acceleration without the trailer [l]	0.021	0.059
Acceleration with the trailer [l]	0.021	0.079

The results are also depicted in the graph in Figure 7.

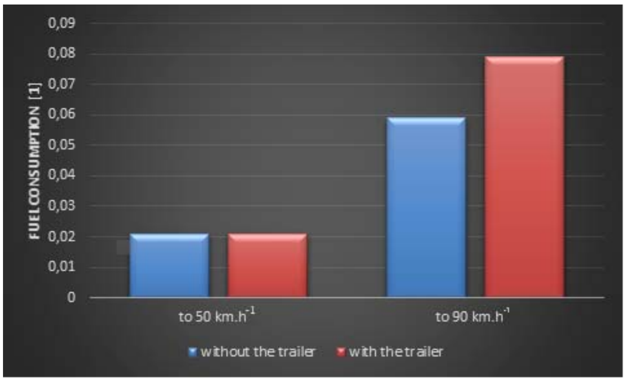

Figure 7. The values measured during the vehicle acceleration

Based on Table 4 and Figure 7, no difference can be observed in the amount of fuel consumption during the vehicle acceleration from zero speed to 50 km·h-1. This can be explained by the fact that there was achieved relatively low speed at which the air resistance reaches low or negligible values. Also, the difference in the vehicle mass represented only the trailer mass i.e. 136 kg. In the case of the vehicle acceleration to 90 km·h-1, the difference in fuel consumption was 0.02 l. The difference was probably caused by the change in the air resistance [20].

4. Conclusion

Based on the measurements, it can be concluded that the driving with the trailer increases fuel consumption, especially at higher speed (in this case 90 km·h-1). The obtained results demonstrate that in terms of fuel consumed the passenger car trailers should be used only in cases when its use is a necessity. The results also show that fuel consumption when using trailers increases with increasing speed. Therefore, it is advisable to drive at lower speed when using a trailer. It is also necessary to take into account the fact that fuel consumption decreased by 0.3 l·100 km-1 at speed 90 km·h-1 after dismantling the trailer frame. The mentioned equipment is currently mounted by the manufacturer on each plastic cover of the trailer Agados. However, the practical use of this equipment is very rare in practice. In terms of fuel consumption, it would be appropriate for the frame to be included among the optional accessories. Thus, the trailer frame would only be suitable for the customer group that assumes its use or for the customers that do not expect to often drive at higher speed. The second alternative could represent such a frame design that would allow easy assembly and removal of the frame. At present, the dismantling of the trailer frame is rather complicated and it requires a cooperation of two persons.

The removal of the plastic cover resulted in fuel consumption increase by 0.2 l·100 km-1 at speed 90 km·h-1. Thus, the plastic cover of the trailer contributed to the reduced fuel consumption. The lowest fuel consumption was measured when driving without the trailer (with cargo transported in the luggage compartment) when no tensile resistance acted on the vehicle [21].

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