

Relationships Between Vehicle Traction Properties and Fuel Consumption for Part Engine Loads

Wawrzyniec Gółbiewski

Department of Automotive Vehicles Operation, West Pomeranian University of Technology in Szczecin
17 Piastów Ave., 70-310 Szczecin, Poland, tel.+48 91 449 40 45, e-mail: wawrzyniec.golebiewski@zut.edu.pl

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Summary. This paper presents the effect of respective vehicle traction properties (acceleration capacity, grade ascending ability, ability to reach maximum speed) on its mileage fuel consumption. These relationships were determined under part engine load conditions for the vehicle speeds being reached in more than one gear ratio. Experiments were carried out based on engine standards according to which the points of the load characteristics curve of engine torque and fuel consumption were created by measurements.

It has been shown that vehicle fuel consumption increases with an increase in its dynamic parameters.

Key words: mileage fuel consumption, passenger car, acceleration capacity, grade ascending ability, maximum speed.

efficiency depends therefore on the car traction properties being used, in other words on its acceleration capacity, grade ascending ability and ability to reach maximum speed [4, 15, 18]. They are presented in Figure 1 below.

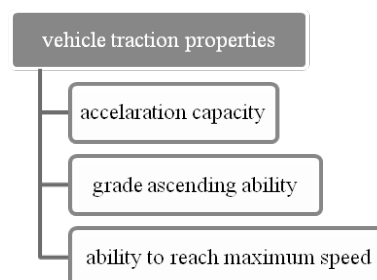


Fig. 1. Division of vehicle traction properties

INTRODUCTION

Mileage fuel consumption is a measure of car energy efficiency but also a variable which depends on a number of factors, such as: vehicle design and technical condition, fuel physical and chemical parameters, road infrastructure, road traffic intensity (including the congestion phenomenon), but also on driver's style of driving [15]. Every man has different psycho-physical traits and may apply any car motion type depending on his / her own preferences. Training of drivers in a driving technique called eco-driving shows that the individual character of vehicle steering technique affects fuel consumption volume [3]. This parameter also affects the emission of toxic and non-toxic compounds (such as, for instance, carbon dioxide being a greenhouse gas monitored by federal agencies [5, 6, 7, 8, 19]) into the atmosphere. The value of fuel consumption is often higher than that being specified by a car manufacturer and this discrepancy results from different traffic characteristics being at variance with a stationary conditions of fuel consumption determination according to predetermined driving cycle (e.g. NEDC, ADAC Ecotest, WLTC) [1, 2, 9, 11, 14, 16]. Vehicle energy

Each of the afore-mentioned parameters is characterised by specific energy consumption of vehicle motion being dependent on total resistance to motion.

The motion of a vehicle on a straight road at a constant speed is conditioned by overcoming by a car the basic resistance to motion (rolling resistance and air resistance). A driving force to compensate the resistance to motion must be generated according to the following equation [4, 18]:

$$F_N = F_t + F_p + \Delta F, \quad (1)$$

where:

F_N – driving force [N],

F_t – rolling resistance [N],

F_p – air resistance [N],

ΔF – driving force reserve [N].

The total contribution of basic resistance to motion in maximum generatable driving force (being obtained with the drive system for specific motion conditions) is small. The difference between the maximum driving force and basic resistance to motion is a driving force reserve. This value can

be used to overcome additional resistance, among others: inertia resistance (acceleration) and/or grade resistance.

Utilisation of the total driving force (accelerator pedal fully depressed) is occasional due to variability in motion conditions, and therefore the use of part engine loads (accelerator pedal partially depressed) during vehicle motion is of importance.

STUDY OBJECTIVE

The aim of this study was to determine and evaluate the relationships between car traction properties and fuel consumption for part engine loads.

TEST BED

Tests were carried out on an engine test bench (Fig. 2) composed of the following elements:

- fuel tank;
- Automex fuel-o-meter,
- EMX100 eddy-current dynamometer,
- programmer,
- FIAT MultiJet 1.3 JTD engine.

Test bench programmer provided the setting of predetermined engine operational parameters, while PARM software allowed reading the values of parameters measured by the sensors being positioned on EMX100 dynamometer and being integral accessories of a drive unit. The latter, on the other hand, was fed with fuel from a fuel tank via a fuel-o-meter being integrated with a fuel gauge used to read fuel consumption.

Engine test bench was composed of a drive unit connected serially to eddy-current dynamometer.

The object of bench testing was a FIAT MultiJet 1.3 JTD engine (compression-ignition, direct injection, four-stroke turbocharged engine with Common Rail fuel injection system). Its basic technical information is presented in Tab. 1.

Tab. 1. Engine manufacturer information [20]

	Unit	Value
Cylinder diameter	[mm]	69.6
Piston travel	[mm]	82
Compression ratio	-	18.1
Number of cylinders	-	4
Arrangement of cylinders	-	in-line
Injection sequence	-	1-3-2-4
Engine capacity	[cm ³]	1248
Maximum power	[KM/kW]	70/51
Rotational speed at maximum power	[min ⁻¹]	4000
Maximum torque	[Nm]	145
Rotational speed at maximum torque	[min ⁻¹]	1750

TEST METHODS

Specific test methods included application of experimental testing and simulation models. The results of empirical tests, in the form of engine load characteristic curve, were obtained using a test bed. The parameters of load characteristic curve were used as input data for a simulation model (Fig. 3). Based on this information, the results of simulation testing were obtained as relationships between vehicle traction properties and fuel consumption.

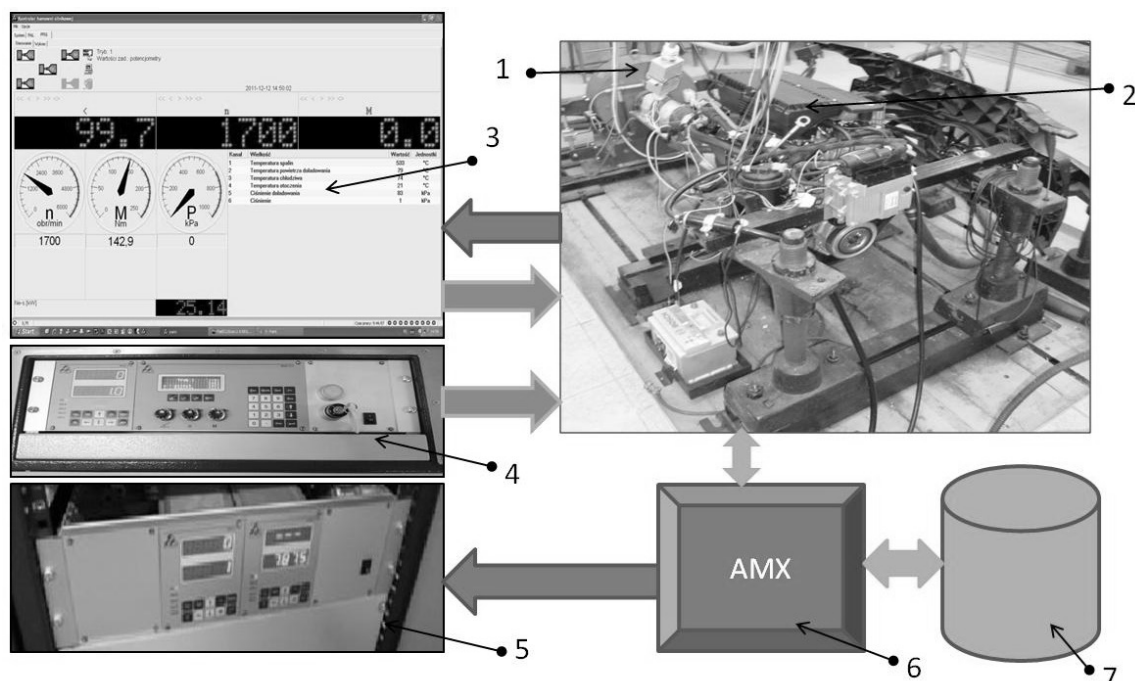


Fig. 2. Pictorial diagram of the test bed: 1 – EMX 100 dynamometer, 2 – FIAT MultiJet 1.3 JTD engine, 3 – PARM 1.7 software, 4 – AMX212 programmer, 5 – AMX212F fuel gauge, 6 – fuel-o-meter, 7 – fuel tank; orange arrows – fuel flow, blue arrows – parameter reading, green arrows – control

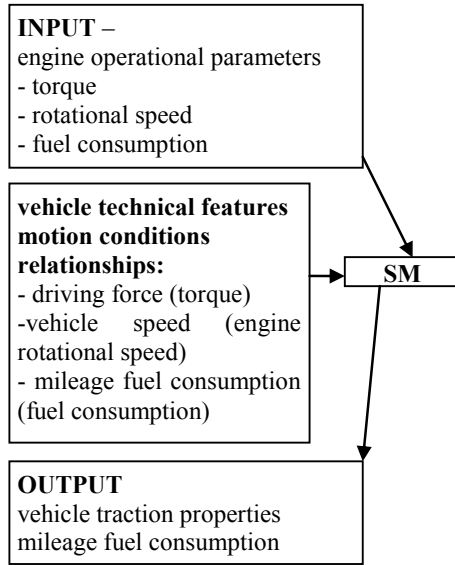


Fig. 3. Simulation test model (SM)

In accordance with the adopted methods, experimental testing provided for the measurement of engine operational parameters, such as: torque, rotational speed or its fuel consumption. Conditions during the testing as well as accuracy of the values being determined were consistent with the standard [17].

TEST OBJECT

The object of simulation tests was a FIAT Panda vehicle equipped with a MultiJet 1.3 JTD engine. This vehicle has been described by technical features and motion conditions (tab. 2).

The data referring to the values of C514R gearbox ratios have been taken from vehicle manufacturer's instruction [20].

Table 2. Vehicle technical features and motion conditions

Vehicle technical features	Value
Maximum gross vehicle weight	1455 kg
Vehicle frontal area	2.19 m ²
Drive system efficiency	0.9
Dynamic wheel radius	0.27 m
Air resistance coefficient c_x	0.33
Motion conditions	
Rolling resistance coefficient (smooth asphalt)	0.012
Air density	1.16 kg/m ³

TEST RESULTS

The measurement of operational parameters allowed creation of the load characteristic curve for a FIAT MultiJet 1.3 JTD 16V engine (Fig. 4).

The load characteristic curve presents engine torque lines as a function of fuel consumption for respective engine rotational speeds (see legend – top right). It allows determi-

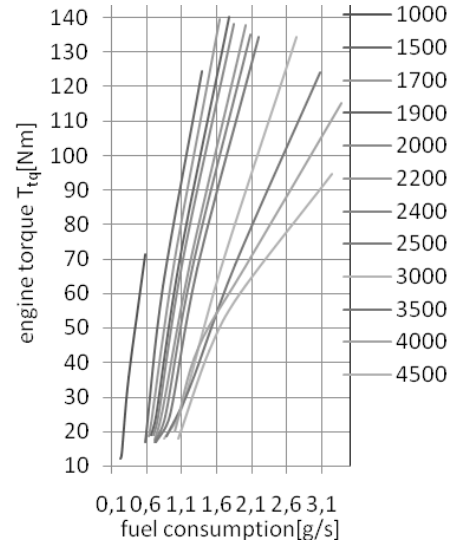


Fig. 4. FIAT MultiJet 1.3 JTD engine load characteristic curve

nation of the value of fuel consumption under part engine load conditions of vehicle movement.

RELATIONSHIPS BETWEEN VEHICLE TRACTION PROPERTIES AND FUEL CONSUMPTION

Defining the relationships between fuel consumption and vehicle dynamic properties, being determined by acceleration capacity and grade ascending ability required a reference to the value of fuel consumption in order to generate a driving force at the wheels needed to overcome specific additional resistance to motion (inertia resistance, grade resistance).

When assuming that part of driving force reserve at the wheels (difference between the maximum driving force on wheels and basic resistance to motion) will be used to overcome inertia resistance, it is possible to determine a number of accelerations which a vehicle is able to reach under given motion conditions and at a given speed.

Applying the values of engine torque characteristic curve (load characteristic curve) as a function of its rotational speed for fuel consumption curves as well as using the vehicle technical features and motion conditions, a vehicle acceleration was determined according to the following relationship [4, 18]:

$$a = \frac{\Delta F}{m \cdot \delta} = \frac{F_N - (F_t + F_p)}{m \cdot (1.04 + 0.03 \cdot i_b^2)}, \quad (2)$$

where:

ΔF – driving force reserve [N],

m – vehicle gross weight [kg],

δ – coefficient of rotating masses,

F_N – driving force [N],

F_t – rolling resistance [N],

F_p – air resistance [N],

i_b – gear ratio.

Mileage fuel consumption was calculated from the following relationship [4, 18]:

$$Q = \frac{B_h \cdot 100}{\rho_p \cdot v}, \quad (3)$$

where:

Q - mileage fuel consumption
[dm³/100 km],

B_h - hourly fuel consumption [kg/h],

ρ_p - fuel density [kg/dm³] (density value adapted for calculation was 0.82 kg/dm³),

v - vehicle speed [km/h].

Using the simulation model, the following was determined:

- traction characteristic curve of fuel consumption for constant acceleration capacity values,
- traction characteristic curve of fuel consumption for constant grade ascending ability values,
- traction characteristic curve of fuel consumption as a function of vehicle speed (gear 4 and gear 5).

The traction characteristic curve of fuel consumption for constant acceleration capacity values is presented in Figure 5.

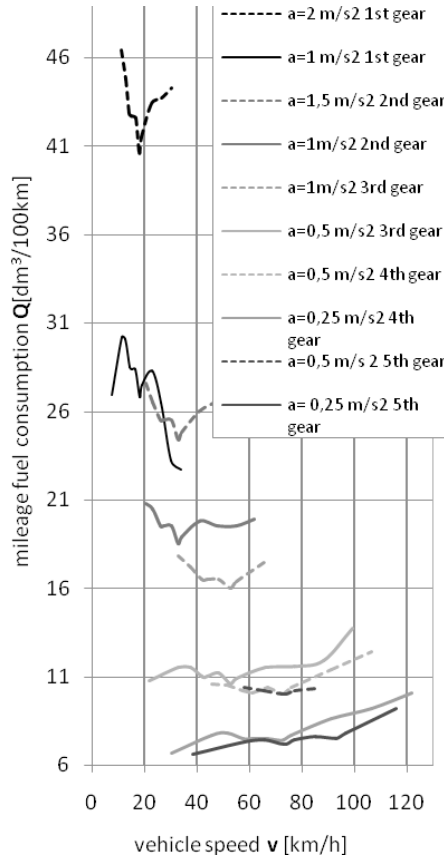


Fig. 5. Traction characteristic curve of fuel consumption Q for constant acceleration values a

The presented diagram shows that:

- highest accelerations were obtained for lower gears,
- higher accelerations for the same gear ratio were achieved at the cost of higher fuel consumption,
- increase of acceleration by 100% for the first gear induced also an increase in fuel consumption by about 51%,
- increase of acceleration in higher gears did not induce such a drastic increase in fuel consumption,

- accelerations reached in the highest gears were the lowest,
- in the speed range of 60 to 85 km/h, the same acceleration (0.5 m/s²) reached in the fourth and the fifth gear induced almost the same fuel consumption (fuel consumption for a lower gear was significantly lower only for upper speed values of the range given).

The next diagram created was the traction characteristic curve of fuel consumption for constant acclivity gradient values (Fig. 6).

Mileage fuel consumption was determined based on the relationship (3), while acclivity gradient was determined from the following formula [4, 18]:

$$p = \frac{\Delta F}{m \cdot g}, \quad (4)$$

where:

p – acclivity gradient [%],

ΔF – driving force reserve [N],

m – vehicle gross weight [kg],

g – gravitational acceleration – 9,81 m/s².

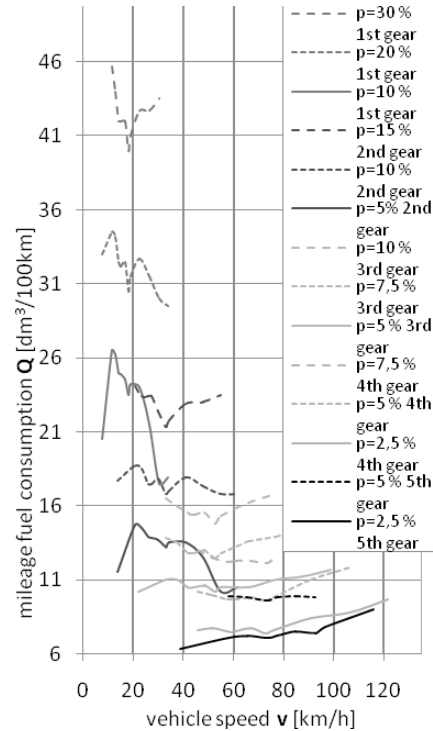


Fig. 6. Traction characteristic curve of fuel consumption Q for constant acclivity gradient values p

Figure 6 shows that the highest fuel consumption occurred for the lowest gears, although fuel consumption decreased with an increase in the gear number. This parameter also depended on the road slope.

The last characteristic curves obtained was the relationship between mileage fuel consumption and maximum speed reaching ability.

By determining the basic resistance to motion for the speeds being reached by a vehicle in gear 4 and gear 5, its maximum speed was determined, being 155 km/h. The tested engine consumed 9.59 dm³/100 km of fuel at this speed. In order to explore changes in fuel consumption more

closely, the characteristic curve of fuel consumption was created as a set of the intersection points of basic resistance to motion lines with the isolines of mileage fuel consumption in the fourth and the fifth gear (Fig. 7).

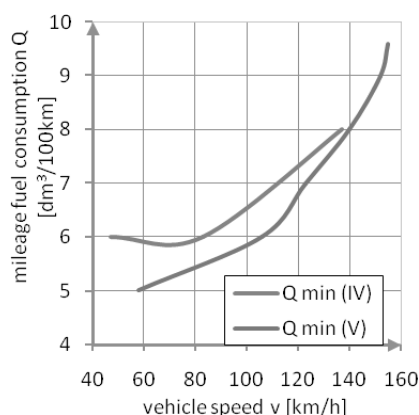


Fig. 7. Characteristic curve of mileage fuel consumption vs. vehicle speed

Based on the presented characteristic curve, it was observed that fuel consumption at the fifth gear increased from the value of 5 dm³/100 km to 9.59 dm³/100 km with an increase in vehicle speed.

It was observed that the results being presented were obtained for basic resistance. Each increase or decrease in resistance to motion, induced for instance by a change in the pavement [road surface] will result in a change in both maximum speed and minimum fuel consumption.

The value of fuel consumption was directly affected by vehicle load to its maximum gross weight. It also was possible to see that a FIAT Panda vehicle with a gross weight of 1455 kg did not have acceleration capacity ($a = 0.03$ m/s²) around maximum speed. By reducing the vehicle weight, the resistance to motion would decrease, which would improve traction properties, and therefore its acceleration capacity at the final gear (larger driving force reserve at the driven wheels), its maximum speed would increase and fuel consumption would decrease.

CONCLUSIONS

Based on the characteristic curves obtained, the following conclusions should be listed:

- lowest fuel consumption for constant gear ratio occurs for engine rotational speed being slightly higher from the rotational speed of maximum torque (one of the main assumptions of eco-driving),
- increase in the values of gear ratio improves vehicle traction properties but induces an increase in fuel consumption,
- knowing the value of driving force at the wheels allows better evaluation of the value of fuel consumption but also analysis of vehicle dynamic parameters.

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RELACJE POMIĘDZY WŁAŚCIWOŚCIAMI
TRAKCYJNYMI POJAZDU A ZUŻYCIEM PALIWA
DLA OBCIĄŻEŃ CZĘŚCIOWYCH SILNIKA

Streszczenie. Artykuł prezentuje wpływ poszczególnych właściwości trakcyjnych (zdolność do przyspieszania pojazdu, zdolność do pokonywania wzniesień, zdolność do osiągnięcia prędkości maksymalnej) na przebiegowe zużycie paliwa pojazdu. Relacje te określono w warunkach obciążeń częściowych dla prędkości samochodu osiągniętych na więcej niż jednym przełożeniu skrzyni biegów. Eksperymenty zostały przeprowadzone na podstawie norm silnikowych, według których przez pomiar utworzono punkty charakterystyki obciążeniowej momentu obrotowego silnika oraz zużycia paliwa.

Wykazano, że wraz ze wzrostem parametrów dynamicznych pojazdu rośnie jego zużycie paliwa.

Słowa kluczowe: przebiegowe zużycie paliwa, samochód osobowy, zdolność do przyspieszania pojazdu, zdolność do pokonywania wzniesień, zdolność do osiągnięcia prędkości maksymalnej.