International Journal of Automotive and Mechanical Engineering (IJAME)
ISSN: 2229-8649 (Print); ISSN: 2180-1606 (Online); Volume 9, pp. 1820-1831, January-June 2014

DOI: http://dx.doi.org/10.15282/ijame.9.2013.29.0151

VALIDATION OF ROAD LOAD CHARACTERISTIC OF A SUB-COMPACT VEHICLE BY ENGINE OPERATION

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ABSTRACT

Vehicle efficiency relates to pollutants and cost savings in third world countries. In terms of sub-compact cars, the vehicle characteristics are governed by the engine and road load characteristics. The main objective was to evaluate the coefficients of rolling resistance and drag on a moving sub-compact car and to compare the results from engine tests on a dynamometer. Tests were conducted on a local sub-compact car to measure engine speed, throttle position and air fuel ratio while Global Positioning Systems (GPS) recorded data of the vehicle's speed and position. Also, dynamometer testing was carried out to determine the vehicle characteristics. The results of an on the road roll down test and cruising test were combined to get the road load characteristics of the vehicle. A comparison of the road loads obtained with the actual engine dynamometer test was found to have about 5% error. The experimental errors show the validation of the tests. The tests show the dynamometer's relation to real life road loads.

Keywords**:** Dynamometer; road loads; onboard measurement;vehicle speed.

INTRODUCTION

A sub-compact vehicle is a vehicle which has between 2407L and 2803L of interior volume, according to the US Environmental Protection Agency (Wu, Zhao, & Ou, 2011). Usually it has a length of 4191 mm but is longer than a micro car. Such cars are usually popular in South-East Asia. This is because in the majority of that region people live in cities and require a small and highly manoeuvrable vehicle without compromising interior volume. Normally a sub-compact vehicle is powered by an internal combustion engine. Internal combustion engines rely on fossil fuel such as gasoline and diesel(Ghobadian, Najafi, & Nayebi, 2013; Mat Yasin, Mamat, Sharma, & Yusop, 2012; Rahim, Mamat, Taib, & Abdullah, 2012). Fossil fuels are a non-renewable form of energy, which implies that there is a finite amount in the world(Azad, Ameer Uddin, & Alam, 2012; Aziz Hairuddin, Wandel, & Yusaf, 2013; Soon, Rus, Anika, & Hasan, 2013; Sundar Raj & Sendilvelan, 2010; Yusaf, Hamawand, Baker, & Najafi, 2013). Also, when fossil fuel burns it produces pollutants including carbon dioxide which contributes to the greenhouse effect, and nitrous oxide which contributes to acid rain (Johnstone & Karousakis, 1999). Therefore the study of vehicle efficiency is important. Vehicle efficiency is governed by the engine of the vehicle and the road load characteristics acting on the vehicle itself. As found by (Tzirakis, Pitsas, Zannikos, & Stournas, 2006), the relation between fuel consumption and vehicle track can be measured by Global Positioning Satellites (GPS). GPS technology is a preferred method of measurement because of its ability to accurately determine position and speed using signals from orbiting satellites (Smith, Morison, Capelle, Christie, & Blair, 2011). Similar tests were carried out by Durell, Allen, Law, and Heath (2000) of the Argonne National Laboratory to evaluate two hybrid electric vehicles both on the road and using a dynamometer for their fuel economy, battery characteristics, engine operation, and overall hybrid control strategy. The results of these tests enable realistic conditions to be simulated on a dynamometer. In this paper the author will concentrate more on the vehicle road load characteristics for a sub-compact car in Malaysia. A correlation between transient vehicle loads and tests on a dynamometer was found. The test can be used in future to determine the driving patterns on the road for the average passenger car in Malaysia and their individual driving cycles.

ROAD LOAD CHARACTERISTIC

The road load characteristic is a formula that describes the vehicle power required to cruise at a certain speed. This power is used to overcome the rolling resistance which comes from the friction of tires and aerodynamic drag of the vehicle. The road load characteristic of a vehicle is governed by Eq.1 (Heywood, 1988):

$$P_r = \left(C_R M_v g + \frac{1}{2} \rho_a C_D A_v S_v^2 \right) S_v \tag{1}$$

where

P_r -Road load power
C_R - Coefficient of rolling resistance,
M_v - Mass of vehicle including the passenger,
g - Acceleration due to gravity,
ρ_a - Ambient air density,
C_D - Coefficient of aerodynamic drag,
A_v - Frontal area,
S_v - Vehicle speed.

As shown in the formula, the rolling resistance of the vehicle is influenced by the coefficient of rolling resistance, C_R and the mass of the vehicle, M_v. Also, the aerodynamic resistance is influenced by the coefficient of drag, C_D, the vehicle frontal area, A_v and the vehicle speed, S_v. At low speed cruising, the rolling resistance of the vehicle consumes more power than the aerodynamic resistance. However, at high speed cruising, the aerodynamic resistance consumes more power than the rolling resistance. The effect is seen in Figure 1 by Moore, Rahman, and Ehsani (1999). The road load data also enables the estimation of the energy demand of the engine or power plant. According to Smith et al. (2011),the engine energy is the sum of opposing forces on the vehicle, as given in Eq. 2:

$$E_{engine} = \sum_{t=0}^{t_n} \left(P_r \right) \tag{2}$$

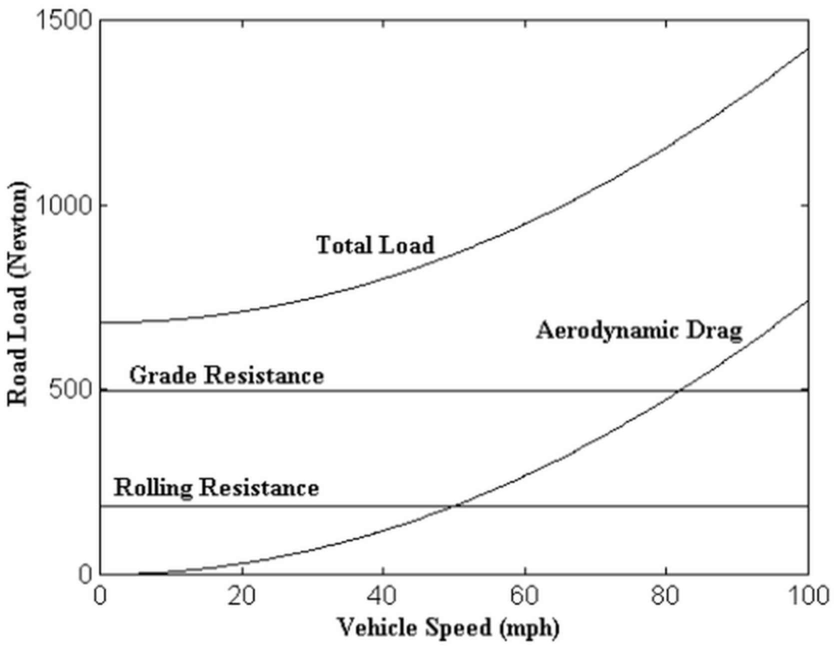

Figure 1. Typical vehicle load function(Moore et al., 1999)

TEST VEHICLE

The vehicle chosen for testing is a sub-compact car from Malaysia and is shown in Figure 2. The specification of the vehicle is as stated in Table 1(DMC, 2012). The specification for the car's engine and transmission is shown in Tables 2 and 3.

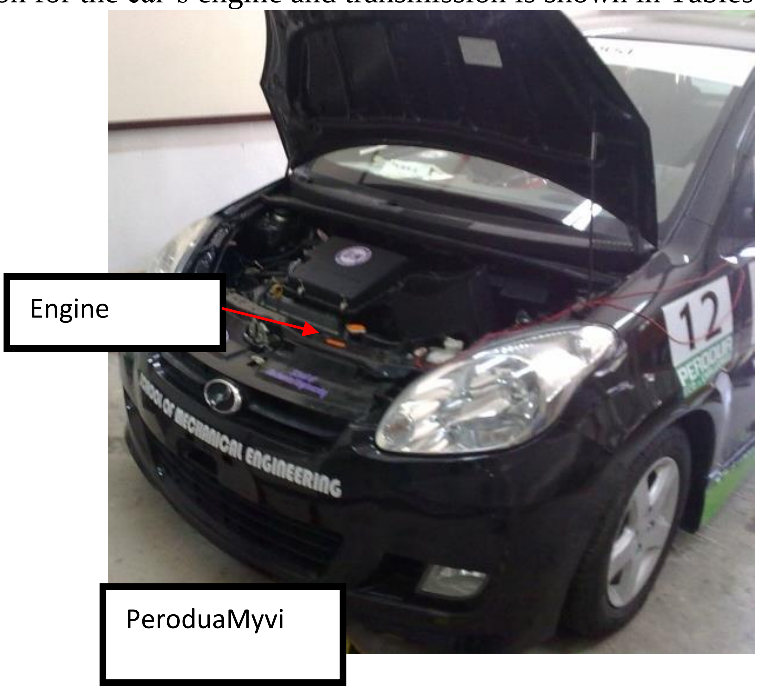

Figure 2.Sub-compact local car in Malaysia

Table 1. Vehicle specification

Parameter	Dimensions
Overall length/width/height (mm)	3690/1665/1545
Wheelbase (mm)	2440
Track front/rear (mm)	1455 / 1465
Tyres (mm)	175/65 R14
Weight (with 2 persons) (kg)	870
Seating capacity (persons)	5

Table 2. Engine specification

Parameter	Specification	
Engine type	K3-VE	
Valve mechanism	DOHC, 16V with DVVT	
Total displacement	1298	cc
Bore X stroke	72.0 X 79.7	mm
Compression ratio	10.0 : 1	
Maximum power output	67/6000	kW/rpm
Maximum torque output	117/4400	Nm/rpm
Fuel system	Electronic fuel injection	

Table 3. Transmission specification

Automatic transmission	Gear ratio
1st	2.731
2nd	1.526
3rd	1.000
4th	0.696
Final reduction	4.032

THE TRACK

The tracks chosen for testing are shown in Figure 3. The location is on the Universiti Sains Malaysia, Engineering Campus in Penang, Malaysia. These tracks are flat and thus minimize the effects of inclination on the results. As found by (Shimizu, Ikeya, & Miyagi, 1988), inclination can have as much as 10% effect on the fuel consumption for each 1 degree increase. The maximum cruising speed for track 1 was determined as 60km/hr (16.67 m/s) and for track 2 is 80 km/hr (22.22 m/s).

Figure 3. Tracks1 and 2

VEHICLE INSTRUMENTATION

The vehicle was instrumented with a data acquisition system which records the engine speed, throttle position and air fuel ratio. The acquired data was saved in a computer for further processing during the test. Meanwhile, to record the moving vehicle, GPS was used to record the vehicle's dynamics, variable of position and speed, as found by (Wu et al., 2011). Figure 4 shows the schematic of the vehicle instrumentation.

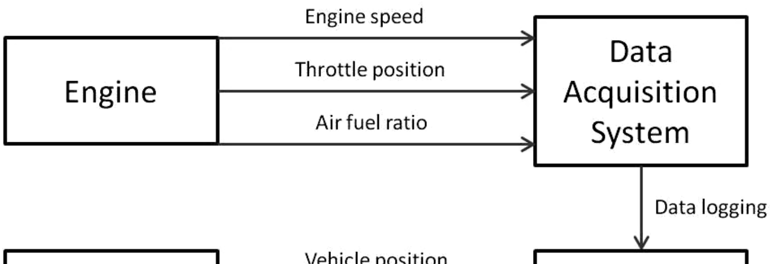

Figure 4. Vehicle instrumentation schematic

ROLL DOWN TEST

In the roll down test, the vehicle was accelerated to about 70 km/hr on track 1. Once the vehicle reached the targeted speed, it was left to roll in neutral gear until it came to a stop. For both rolling resistance and drag in this case it was assumed that the wind effect could be neglected in the test, as found by (Roussillon, 1981). When the vehicle started to roll, the vehicle speed was recorded using GPS. This process was repeated to minimize the influence of wind on the data collected. With the data obtained from the roll down test, a road load power curve was generated.

CRUISING TEST

In the cruising test, the vehicle was moving at a constant speed, and the speeds recorded were 10 km/hr, 20 km/hr, etc. When the vehicle reached the desired constant speed, the engine speed, throttle position and air fuel ratio were recorded with a data acquisition system. The maximum cruising speed of the vehicle on track 1 was 60 km/hr and on track 2 80 km/hr. The important parameters are the engine speed and throttle position. The air fuel ratio values were used to do a cross-check when the engine was on an engine dynamometer.

ENGINE DYNAMOMETER

After the roll down test and cruising test, the engine in the vehicle was taken out and put on an engine dynamometer with all the engine systems intact as per the manufacturer's specification. Data from the cruising test was used to operate the engine at conditions similar to those used on the road tests at the given speeds. The data from the engine dynamometer, such as engine speed and torque, were recorded using the data acquisition system. Figure 5 shows a schematic of the engine dynamometer. The collected data was then processed to generate an actual road load power graph, which was then compared with the data collected from GPS.

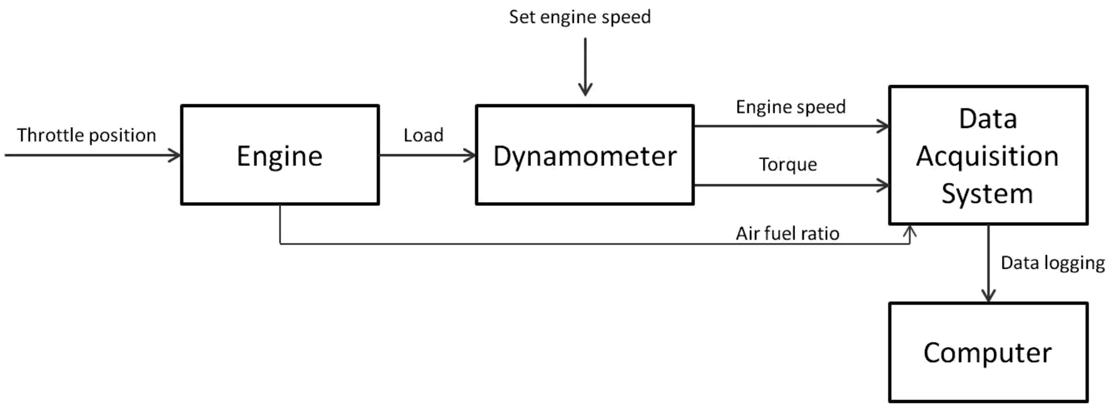

Figure 5. Engine dynamometer schematic

RESULTS AND DISCUSSION

All the data was processed in a spreadsheet. Figure 6 shows the raw data obtained for all the tests carried out. The data was filtered for the best points and six of the tests were examined further. As seen in Figure 6, all the data show good correlation with each test. The curves peak when the vehicle is accelerating and dip when the vehicle is decelerating. To determine the best experiment points for each case, curve fitting of the data was done. Table 4 shows the constant values used for the curve matching of the road load. Figure 7 shows the comparison between the raw experimental data and the curve fitting. A total of seven tests were conducted to obtain the drag and rolling coefficients.

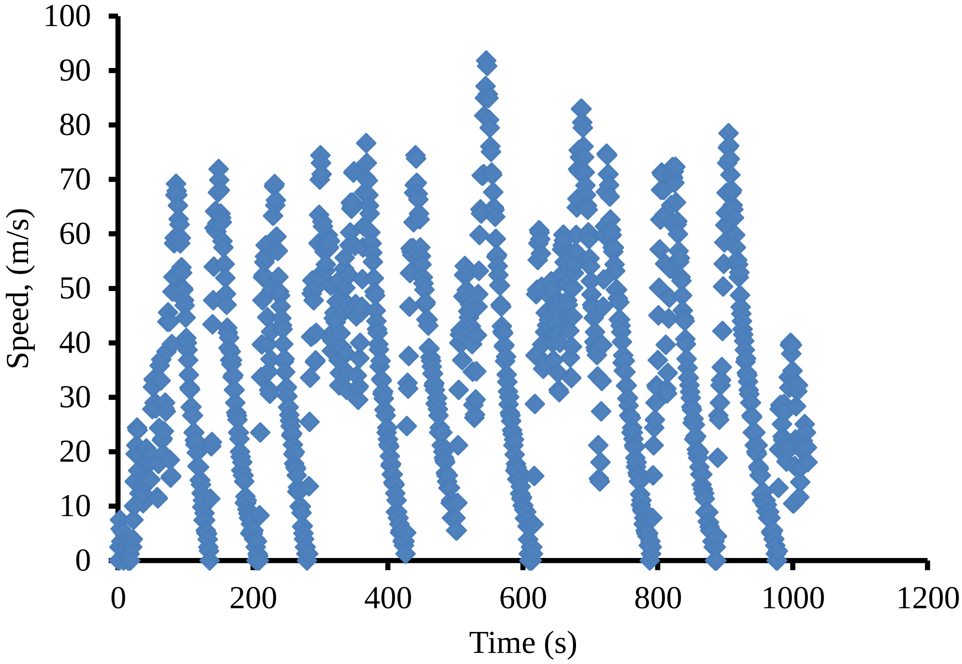

Figure 6. Data taken from the roll down test

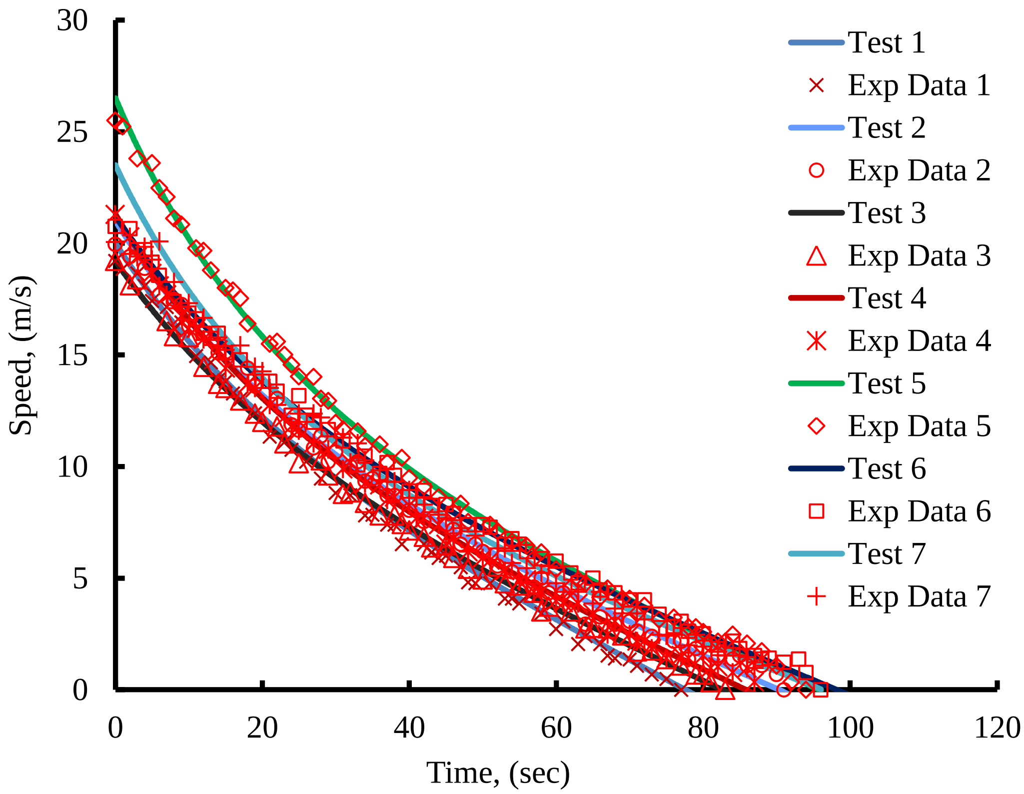

Figure 7. Experimental roll down tests conducted on track

The curve matching was done using Eq. 1, in which the coefficients of drag and rolling resistance values were obtained once the experimental graph coincided with the curve fitting. Once the values of the coefficients of drag and rolling resistance matched the GPS data, the variables were recorded. Table 5 shows the values of the coefficients of drag and rolling resistance for each test recorded from Figure 7. By using the overall averaged data for C_D and C_R at each test point, the simulated road power values can be plotted, as shown in Figure 8. The trend of Figure 8 matches perfectly with Figure 1's theoretical data based on Eq. 1. A maximum load of 32.2 kW was obtained at 120 km/h and it follows the quadratic form due to the square of velocity, S_v.

Table 4. Constants used in the equation

Constants	Values	
Mass of the vehicle including people onboard	870	kg
Acceleration of gravity	9.81	m/s^2
Air density	1.14	kg/m^3
Frontal area of vehicle	2.6	m^2

Table 1. Coefficients of rolling resistance and drag from roll down test

Test number	Coefficient of rolling resistance, C_R	Coefficient of drag, C_D
Test 1	0.49	0.0180
Test 2	0.50	0.0150
Test 3	0.50	0.0160
Test 4	0.52	0.0160
Test 5	0.52	0.0155
Test 6	0.45	0.0140
Test 7	0.45	0.0135
Average	0.490	0.0154

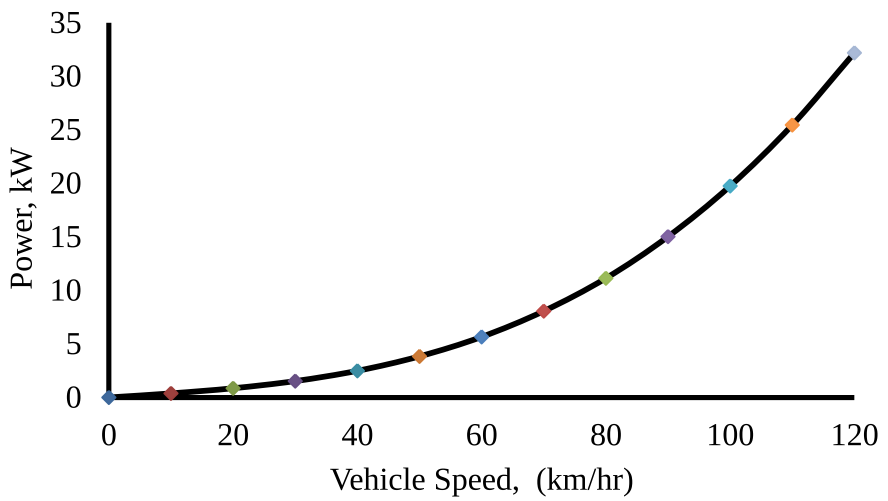

Figure 8. Simulated road power using average data from roll down test

After the simulated data was obtained from Figure 8, an experiment to mimic road load conditions in real life was carried out. The load value was obtained from the TPS position of the vehicle travelling at a constant speed. The values were obtained together with the vehicle gear settings for each speed. Table 6 shows the values of gear position and throttle position at specific vehicle speeds obtained from the cruising tests on tracks 1 and 2. The engine speed was calculated by using the gear ratio found in Table 3 and the throttle position sensor (TPS) signal from the engine. The values were then used as dynamometer settings to find the real loads on the engine. This was done using the data from Table 6,andthe value of torque and engine speed was recorded for each case. A plot of the power required curve for the dynamometer was made.

Table 6. Data from engine vehicle testing and dynamometer

		Vehicle testing		Dynamometer	
Vehicle speed (km/hr)	Engine speed (RPM)	Gear	TPS (V)	Torque (Nm)	Power (kW)
10	1100	1	0.62	4.0	0.46
20	1300	2	0.67	6.0	0.82
30	1200	3	0.65	9.5	1.19
40	1600	3	0.70	13.1	2.19
50	1400	4	0.75	23.2	3.40
60	1700	4	0.82	27.6	4.91
70	2000	4	0.89	37.7	7.90
80	2300	4	0.95	45.0	10.84

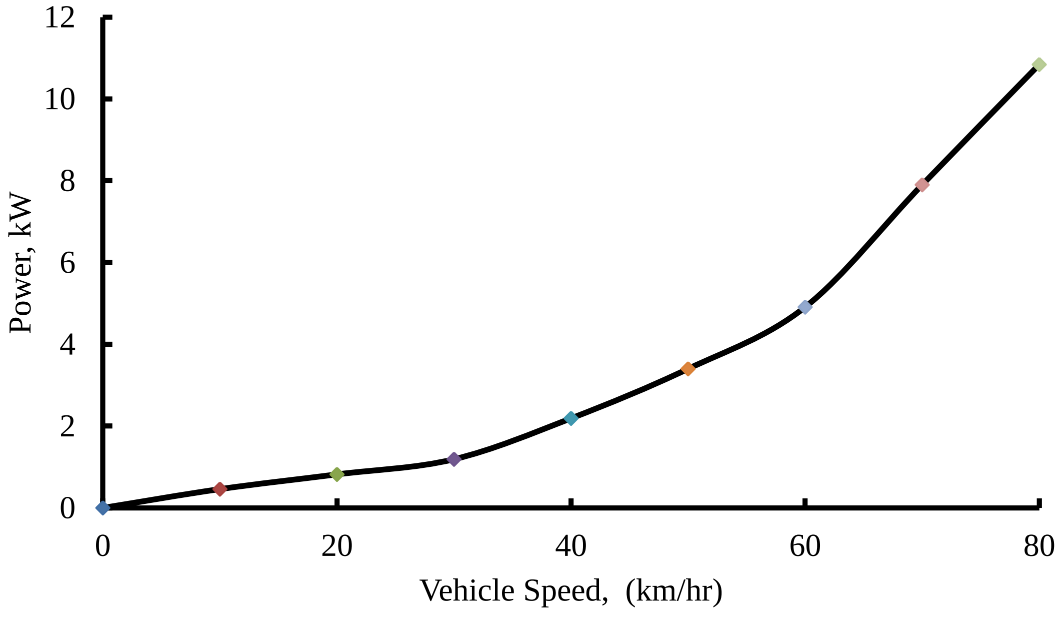

Figure 9. Road power from engine dynamometer data

Figure 9 shows the graph of road power as measured by the dynamometer. A maximum of 10.84 kW was obtained at 80 km/h. When compared to Figure 8, 80km/h was calculated as 11.14 kW. As such, a loss of 2.7% occurred. This error reading of the theoretical and experimental data was considered small and in the acceptable region, as found by (Roussillon, 1981) where 5–15% model and experiment deviation was acceptable. Figure 10 shows the theoretical simulated data with the experimental engine operation data. The data shows a good relationship with the engine operation data. Overall, the theoretical data shows slightly higher power than the experiment on the dynamometer. A 5% error bar allotted to Figure 15 shows good fitting from both the experiment with the dynamometer and the theoretical model from Eq.1. The error occurred only at midrange speed in the experiments, that is, from 30 to 70 km/hr. At higher speeds, the higher forces seem to equal the dynamometer results. However, at the slow speed of 10 km/hr the reading deviated due to higher fluctuation as the engine speed was near idling. The theoretical assumption should give a more positive reading, due to some unavoidable systematic errors in the experiments. This may occur as the result of any slight inclination of the road which was ignored earlier in the calculation. The heating and cooling in the transient road load may also cause this small difference, since the dynamometer only considers one setting for the temperature value.

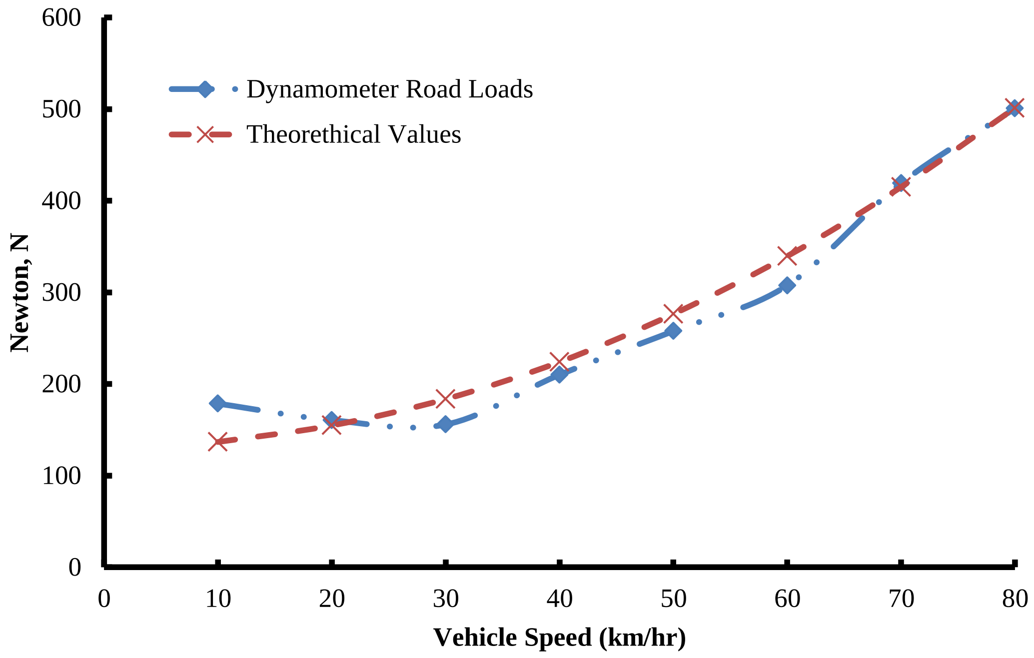

Figure 10. Road load data comparison between data from roll down test and engine dynamometer

CONCLUSIONS

The vehicle characteristics such as the coefficient of rolling resistance and coefficient of drag can be predicted by using GPS. The data can then be validated with engine operations using a dynamometer. With these coefficients known, it is possible to simulate the road load power demand on an engine dynamometer. For this dynamometer, a compensation of 5% error may be required when the final results of the simulation and experiments are compared. The results will enable road loads to be simulated on a dynamometer with minimal errors.

ACKNOWLEDGMENTS

The authors would like to thank the Faculty of Mechanical Engineering in Universiti Sains Malaysia (USM) and MOSTI for financial support under MOSTI Science Fund (Optimization of Combustion for Compressed Natural Gas (CNG) Fuel Engine: 6013388).

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