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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 term of subcompact cars, the vehicle characteristics are governed by the engine and road load characteristics. Overall, it involves the rolling resistance and aerodynamics loading on the moving car on the road. Tests were conducted on a local subcompact car to measure engine speed, throttle position and air fuel ratio while Global Positioning Systems (GPS) recorded data of the vehicle speed and position. Also, dynamometer testing was done to reflect the vehicle characteristics. The results of 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 actual engine dynamometer test was found to have about 5% error. The errors of the experiments shows the validation of the tests.

***Keywords*:** Dynamometer; GPS; Road load

INTRODUCTION

Sub compact vehicle is a vehicle which has between 2407L to 2803L of interior volume according to US Environmental Protection Agency (Anon, 2012). Usually it has a length of 4191mm in length but longer than a micro car's length. Such car characteristic is usually popular to South-East Asian region. This is because majority of South-East Asia people lives in cities which require a small and high manoeuvrability vehicle without compromising interior volume.

Normally sub-compact vehicle is powered by an internal combustion engine. Internal combustion engines rely on fossil fuel such as gasoline and diesel. Fossil fuel is a non-renewable energy which implies that it has a finite amount in the world . Also when fossil fuel burns it produces pollutant such as carbon dioxide which will contribute to greenhouse effect, nitrous oxide which contributes to acid rain and others (N. Johnstone et. al, 1999). Therefore the study of vehicle efficiency is important.

Vehicle efficiency is governed by engine of the vehicle and the road load characteristics acting on the vehicle itself. As found by (E.Tzirakis et. al, 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 et al., 2011). Similar test were carried out by, (Carlson et al., 2007) to evaluate two hybrid electric vehicles both on the road and dynamometer for their fuel economy, battery characteristics, engine operation, and overall hybrid control strategy of two hybrid electric vehicles. The results of these test enables some 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 the future to determine the driving patterns on the road for the average passenger car in Malaysia and their individual driving cycles as found by (Tzirakis, 2006).

ROAD LOAD CHARACTERISTIC

The road load characteristic is a formula that describes the vehicle power requirement to cruise at a certain speed. This power is used to overcome 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, rolling resistance of the vehicle, is influenced by the coefficient of rolling resistance, C_R and the mass of 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 from Figure 1 by (Moore et al., 1999). The road load data also enable the estimation of energy demand of the engine or power plant. According to Smith (2011), the engine energy is the sum of opposing forces on the vehicle which is given by Eq. 2.

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

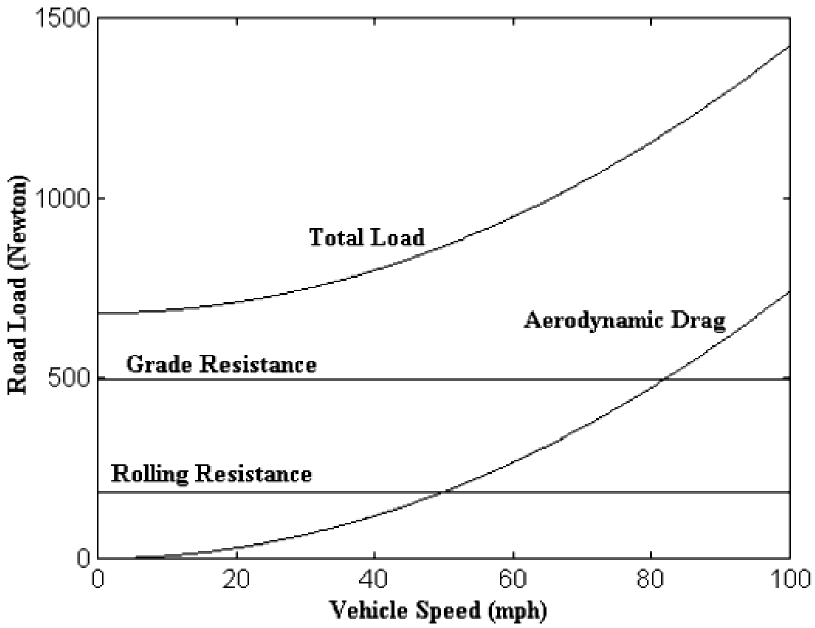

Figure 1: Typical Vehicle Load Function

TEST VEHICLE

The vehicle which has been chosen to test is a sub compact car from Malaysia. The car is as shown in Figure 2. The specification of the vehicle is as stated in Table 1 (Daihatsu Motor Company Ltd., 2012). The specification for the engine and transmission for the car is as shown in Table 2 and 3.

Figure 2: Subcompact 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 person) (kg)	870
Seating capacity (Person)	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 which are chosen for testing are shown in Figure 3 and 4. The location is on Universiti Sains Malaysia, Engineering Campus in Penang, Malaysia. The tracks chosen are flat to minimize the effects of inclination on the results. Inclination can have as much as 10% effect on the fuel consumption for 1 degree increase (K. Shimizu et al., 1988). The maximum cruising speed for track 1 was determined as 60 km/hr (16.67 m/s) and for track 2 is 80 km/hr (22.22 m/s).

Figure 3: Track 1

Figure 4: Track 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 (Changxu Wu et al., 2011). Figure 5 shows the schematic of the vehicle instrumentation.

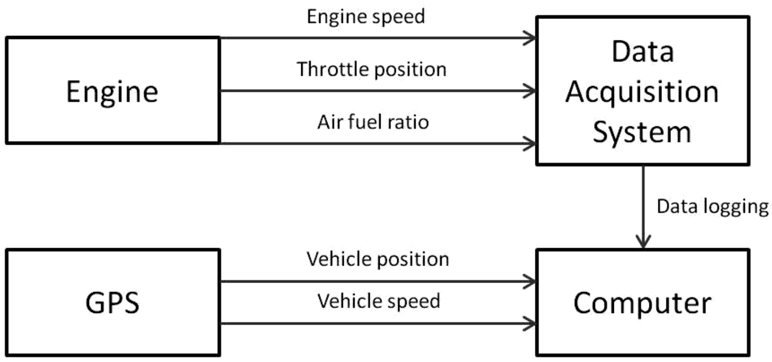

Figure 5: Vehicle instrumentation schematic

ROLL DOWN TEST

In a roll down test, the vehicle is accelerated to about 70 km/hr on track 1. Once the vehicle has reached the targeted speed, the vehicle was left to roll in neutral gear until it reached to a stop. Both rolling resistance and drag in this case were assumed that wind effect is neglected in the test as found by (Roussillon G., 1981). When the vehicle started to roll, the vehicle speed was recorded by using GPS. This process is repeated to minimize the influence of wind to 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 will be moving at a constant speed, the speeds recorded are from 10 km/hr, 20 km/hr and etc. When the vehicle reached the desired constant speed, the engine speed, throttle position and air fuel ratio was 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 is 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 engines systems intact as per manufacturer specification. Data from the cruising test was used to operate the engine at conditions similar to the on the road tests at certain speed. The data from the engine dynamometer such as engine speed and torque is recorded by using a data acquisition system. Figure 6 shows a schematic of the engine dynamometer. The collected data was then processed to generate an actual road load power graph. The road load power graph was then compared with the data collected from GPS.

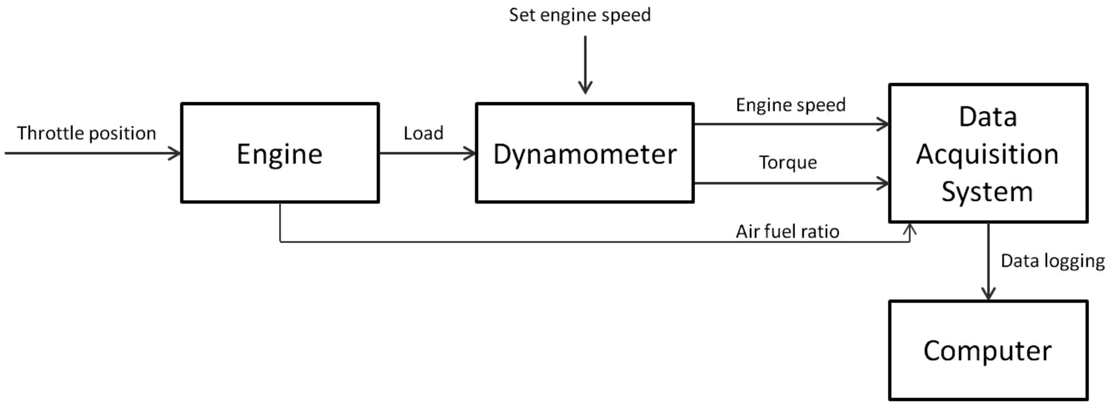

Figure 6: Engine dynamometer schematic

RESULTS AND DISCUSSION

All the data was processed in spreadsheet. Figure 7 shows the raw data obtained for all the test carried out. The data was filtered for the best points and six of the tests were examined further.

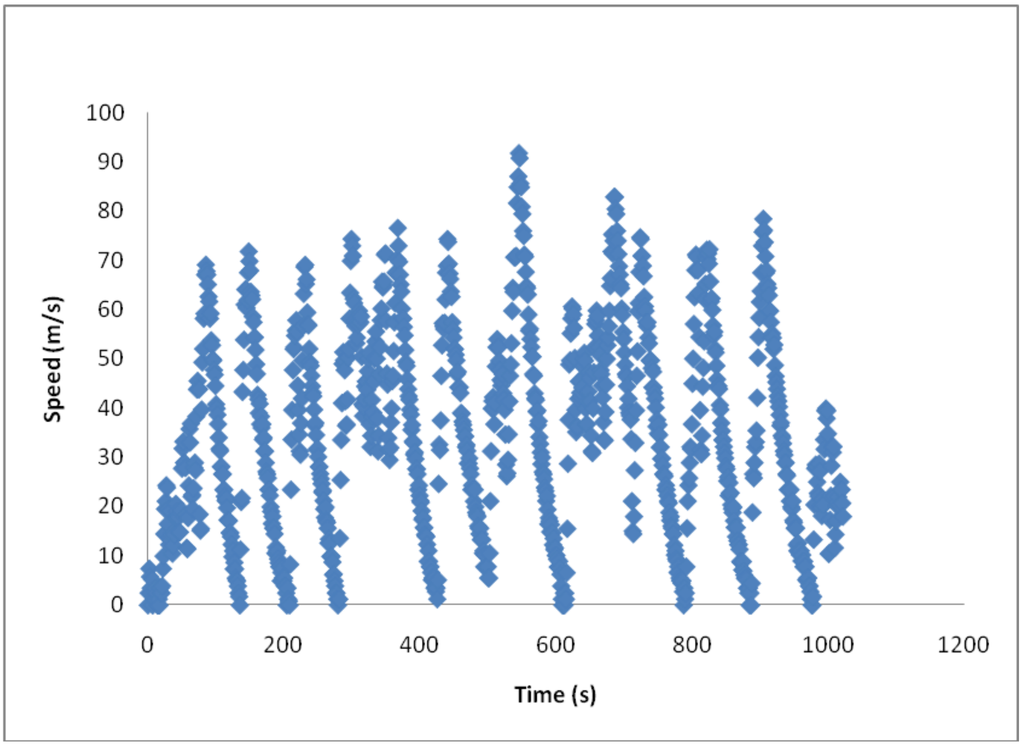

Figure 7: Data taken from the roll down test

As seen in Figure 7 all the data show good correlation with each test. The curves peaks when the vehicle is accelerating and dips when 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 fitting of the road load. Figure 8-13 shows the comparison between the raw data and the curve fitting.

Table 4: Constant 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

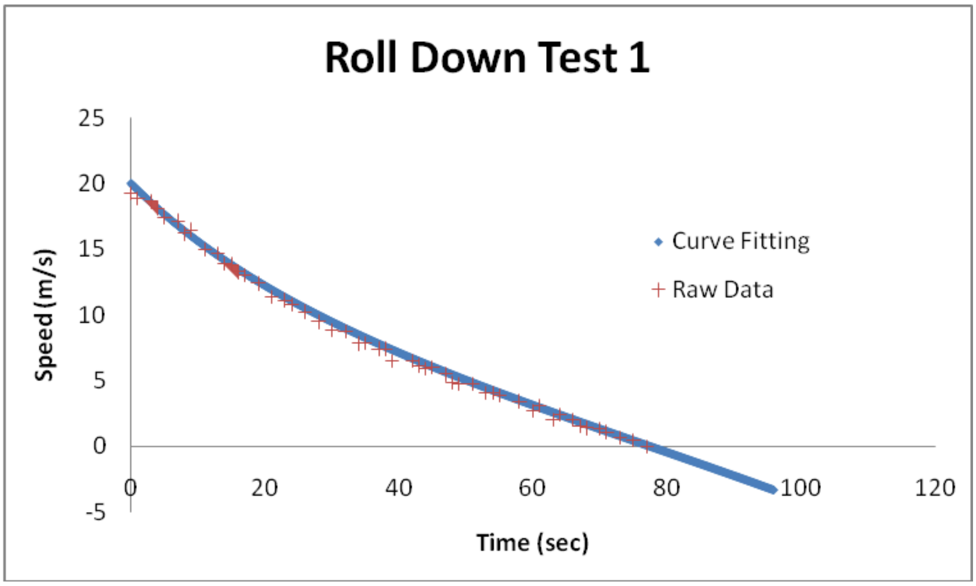

Figure 8: Roll Down Test 1

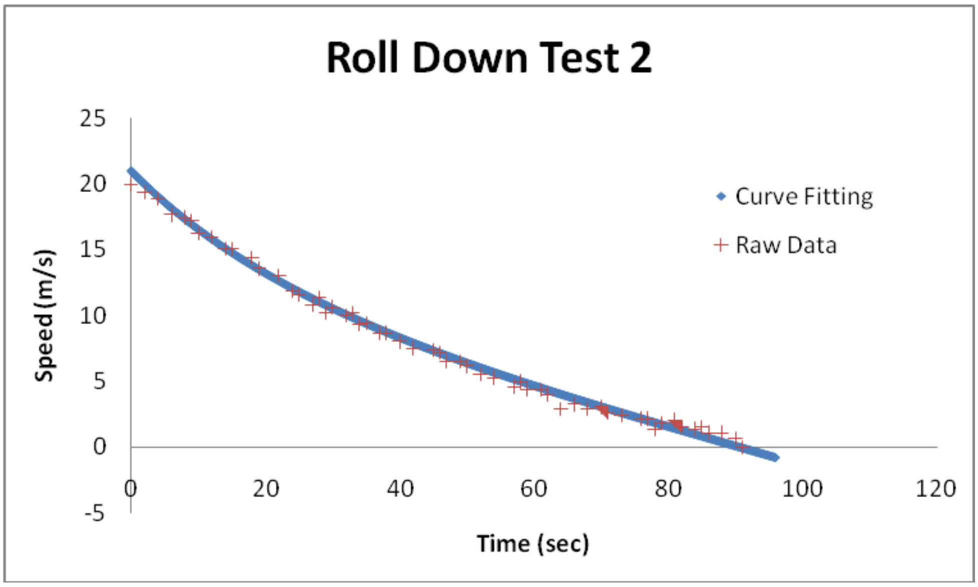

Figure 9: Roll Down Test 2

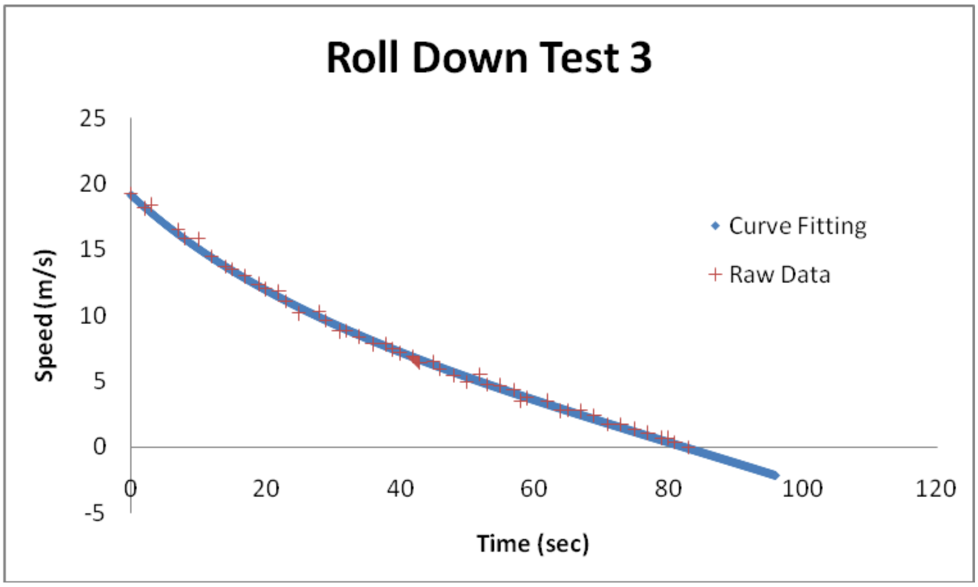

Figure 10: Roll Down Test 3

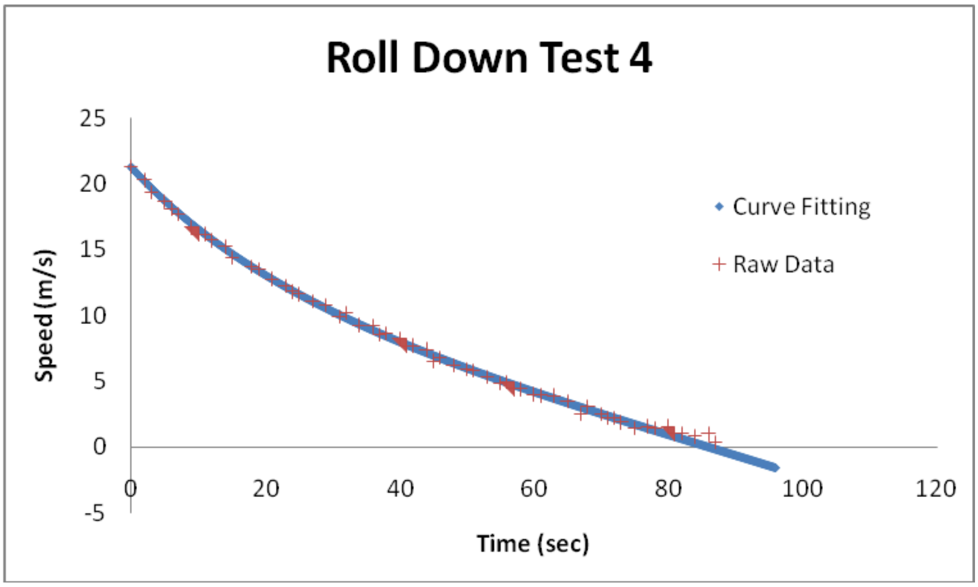

Figure 11: Roll Down Test 4

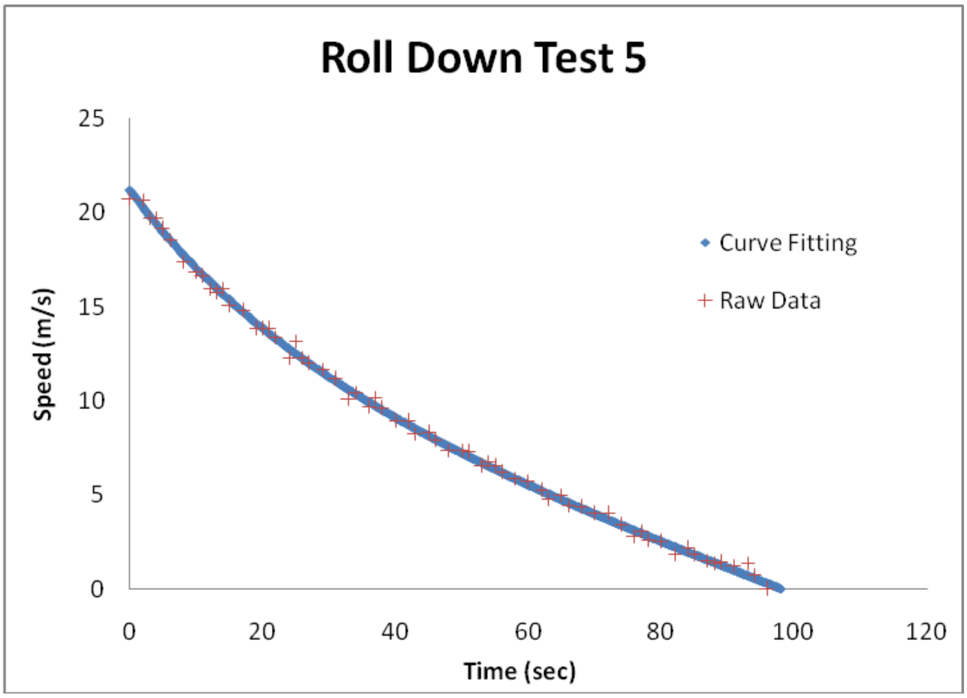

Figure 12: Roll Down Test 5

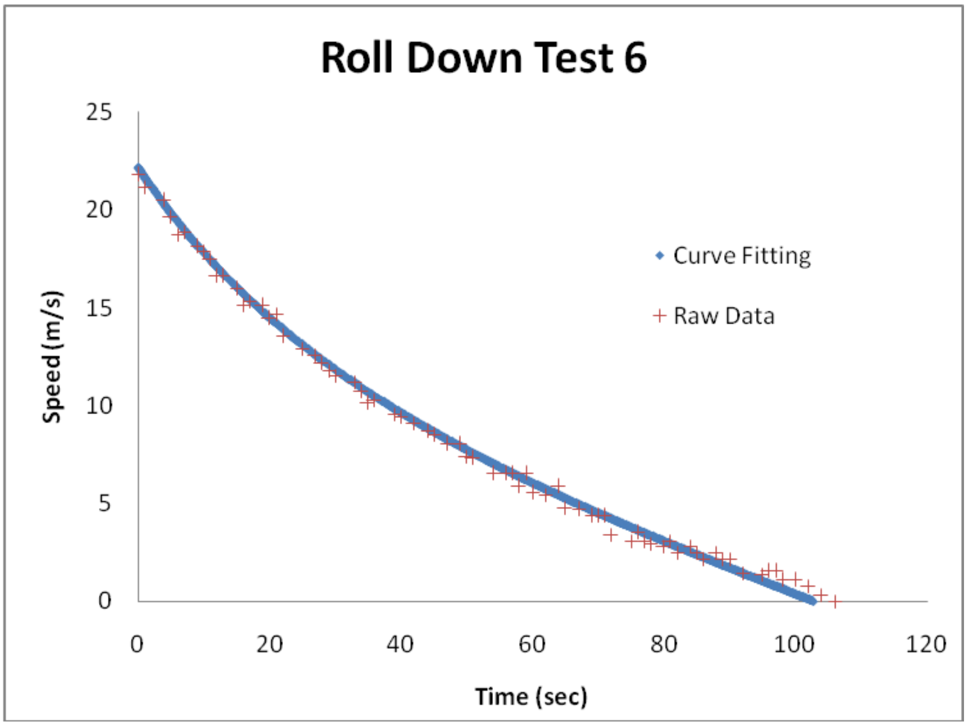

Figure 13: Roll Down Test 6

The figures for the roll down test shows that the data points from experiment follows a trend from the curve fitting line plotted. The curve fitting is done using Eq. 1 in which the coefficient of drag and rolling resistance values are obtained. Once the value of coefficient of drag and rolling resistance matches the GPS data, the variables are recorded. Table 5 shows the average values of coefficient of drag and rolling resistance for each test. By using the overall averaged data for each test point the simulated road load values are plotted. Figure 14 shows the simulated road load versus vehicle speed. The trend of Figure 14 matches perfectly with Figure 1 theoretical data.

Table 5 Coefficient of rolling resistance and coefficient of 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

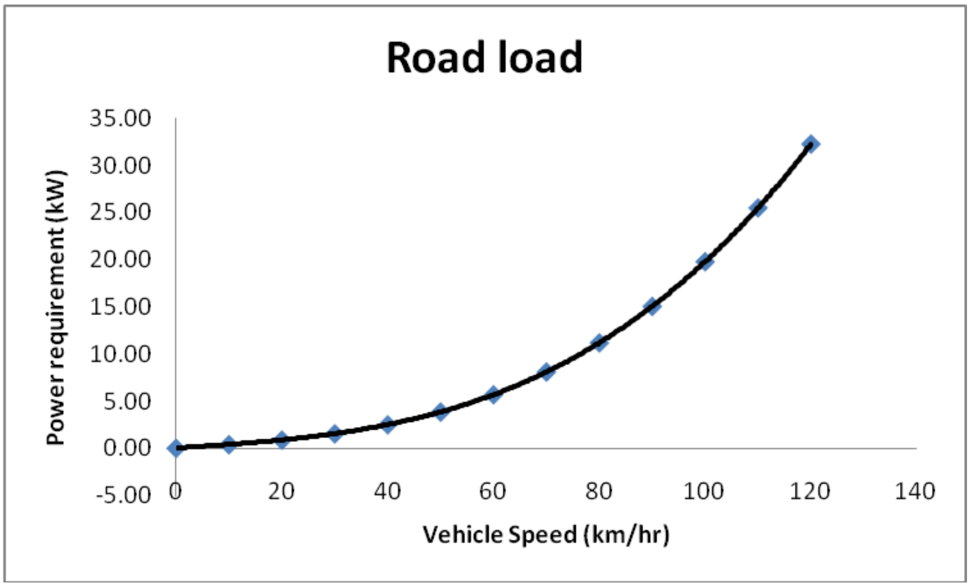

Figure 14: Simulated road load using average data from roll down test

After the simulated data was obtained from Figure 14, experiment to mimic road load condition in real life was done. The load value is obtained from the TPS position of the vehicle travelling on a constant speed. The values are obtained together with the vehicle gear settings for each speed. Table 6 shows the values of gear position and throttle position at a specific vehicle speed obtained from the cruising tests of tracks 1 and 2.

Table 6: Data from cruise test

Speed (km/hr)	Gear	TPS (V)
10	1	0.62
20	2	0.67
30	3	0.65
40	3	0.70
50	4	0.75
60	4	0.82
70	4	0.89
80	4	0.95

The engine speed was calculated by using the gear ratio found in Table 3 and Throttle Position Sensor (TPS) signal from the engine. The values are then used as dynamometer settings to find the real loads on the engine. This was done using the data from Table 7, with the value of torque and engine speed is recorded for each case. A plot of the power required curve for dynamometer was done. Figure 15 shows the graph of road load power and torque as measured by the dynamometer. The trend is again similar to theoretical and simulated conditions.

Table 7: Data from engine dynamometer

Vehicle Speed (km/hr)	Engine Speed (RPM)	Torque (Nm)	Power (kW)
10	1100	4.0	0.46
20	1300	6.0	0.82
30	1200	9.5	1.19
40	1600	13.1	2.19
50	1400	23.2	3.40
60	1700	27.6	4.91
70	2000	37.7	7.90
80	2300	45.0	10.84

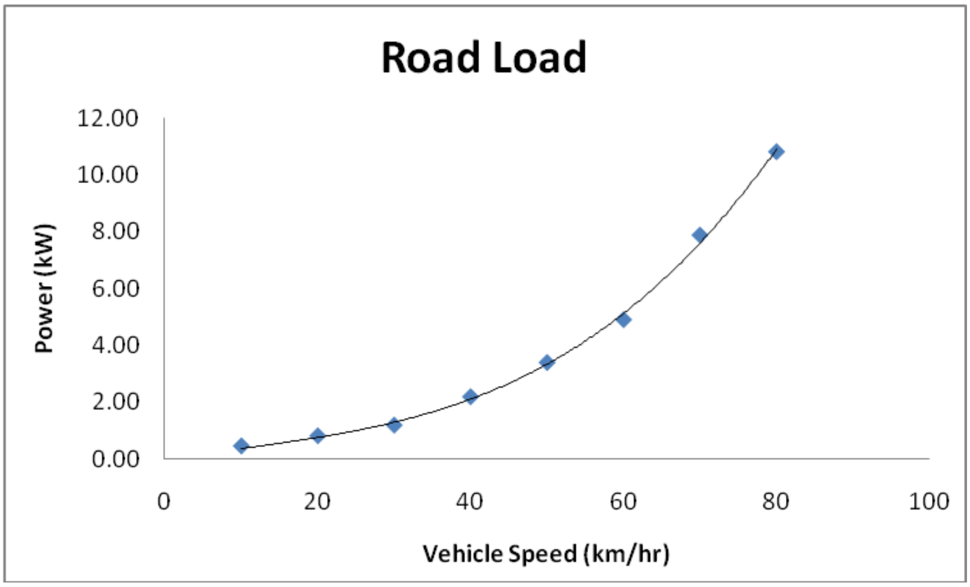

Figure 15 : Road load power from engine dynamometer data

Figure 16 shows the simulated data with the engine operation data. The data shows good relationship with the engine operation data. Overall the theoretical data shows slightly higher power than the experiment on dynamometer. A 5 % error bar allotted to Figure 16 shows good fitting from both experiment and simulation models.

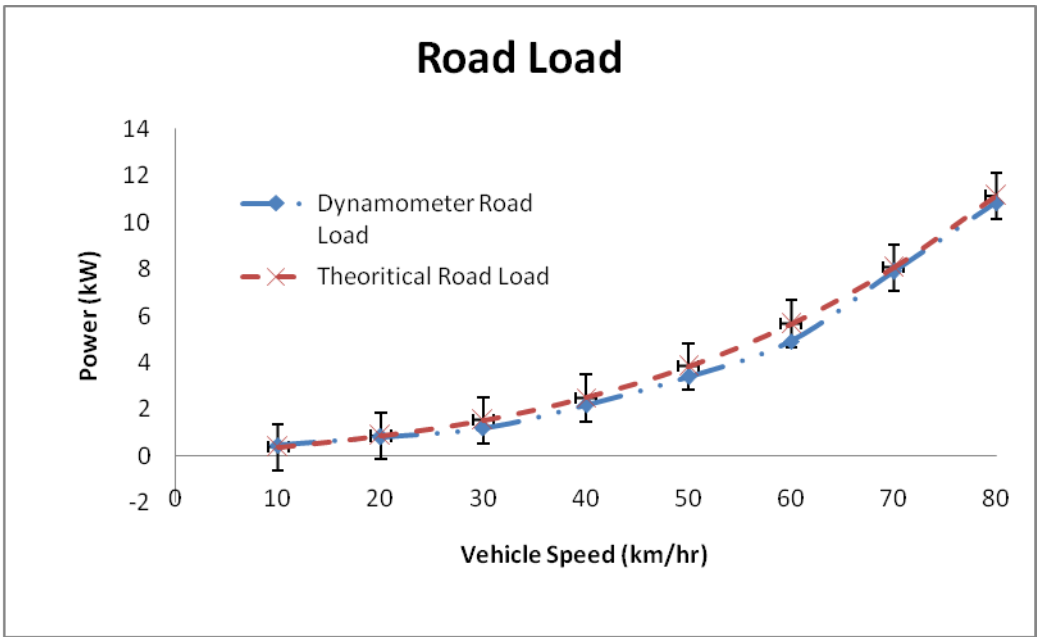

Figure 16: Road load data comparison between data from roll down test and engine dynamometer

The error occurred only at midrange speed of the experiments from 30 to 70 km/hr. The theoretical assumption should give a more positive reading due to some unavoidable systematic errors in the experiments. This may occur as there may be 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 temperature value.

CONCLUSION

In conclusion, the vehicle characteristic such as coefficient of rolling resistance and coefficient of drag can be predicted by using GPS. The data can be then be validated with engine operations. With these coefficient known, it is now possible to simulate road load power demand on an engine dynamometer. A compensation of 5 % error may be required when final results are compared between simulation and experiments.

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REFERENCES

Anon, 2012. Light-Duty Automotive Technology , Carbon Dioxide Emissions , and Fuel Economy Trends: 1975 Through 2011 Light-Duty Automotive Technology , Carbon Dioxide Emissions , and Fuel Economy Trends: 1975 Through 2011. United States Environmental Protection Agency, EPA-420-R-(March 2012).

Changxu Wu, Guozhen Zhao, Bo Ou, 2011. A fuel economy optimization system with applications in vehicles with human drivers and autonomous vehicles, Transportation Research Part D: Transport and Environment, Volume 16, Issue 7, October 2011, Pages 515-524, ISSN 1361-9209, 10.1016/j.trd.2011.06.002.

Daihatsu Motor Company Ltd., 2012. Annual report 2011, Available at: http://doi.wiley.com/10.1111/epp.2606.

E.Tzirakis, K. Pitsas, F.Zannikos, S.S., 2006. Vehicle Emissions And Driving Cycles: Comparison Of The Athens Driving Cycle (ADC) With Ece-15 And European Driving Cycle (EDC). Global Nest, 8(3), 282-290.

Heywood, J.B., 1988. Internal Combustion Engine, New York: McGraw-Hill, Inc.

K. Shimizu, C. Ikeya, M. Miyagi, 1988. Onboard measurement of road inclination, Measurement, Volume 6, Issue 2, April–June 1988, Pages 87-93, ISSN 0263-2241, 10.1016/0263-2241(88)90009-7.

Moore, S.W., Rahman, K.M. & Ehsani, M., 1999. SAE Technical Effect on Vehicle Performance of Extending the Constant Power Region of Electric Drive Motors. SAE Technical Paper Series, 1999-01-11(724).

N. Johnstone, K. Karousakis, 1999. Economic incentives to reduce pollution from road transport: the case for vehicle characteristics taxes, Environmental Economics Programme, International Institute for Environment and Development, 3 Endsleigh Street, London WC1H 0DD, UK, Transport Policy 6 (1999) 99–108

Richard Carlson, Micheal Duoba, Danny Bocci, Henning Lohse-Busch, 2007. On-Road Evaluation of Advanced Hybrid Electric Vehicles over a Wide Range of Ambient Temperatures. 23rd Electric Vehicle Symposium in Anaheim, 275.

Roussillon G., 1981. Contribution to accurate measurement of aerodynamic drag on a moving vehicle from coast-down tests and determination of actual rolling resistance, Journal of Wind Engineering and Industrial Aerodynamics, Volume 9, Issues 1–2, November 1981, Pages 33-48, ISSN 0167-6105, 10.1016/0167-6105(81)90076-3.

Smith R., Morison M., Capelle D., Christie C., Blair D., 2011. GPS-based optimization of plug-in hybrid electric vehicles' power demands in a cold weather city, Transportation Research Part D: Transport and Environment, Volume 16, Issue 8, December 2011, Pages 614-618, ISSN 1361-9209, 10.1016/j.trd.2011.08.008.