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COMPARISON OF POWERTRAIN ALTERNATIVES FOR MANUAL TRANSMISSION VEHICLES USING ONE NUMERICAL MODEL

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Abstract. *During initial phases of vehicle design, the adequate selection of a particular powertrain between available options reduces development time and cost. The correct selection avoids the repetition of costly and time consuming tests. Simulation is one important tool that conducts the designer to a powertrain choice more appropriate to a given vehicle and, at the same time, satisfying consumption specifications. In this work, one numerical model based on longitudinal vehicle dynamics is presented. The simulation program that implements the model is able to predict fuel consumption when the vehicle is submitted to EPA cycles (Urban and Highway). The results obtained with simulation are validated through comparison with tests conducted with a real vehicle.*

Keywords: *transmission, vehicle, fuel consumption*

1. INTRODUCTION

The proposed model is based on simplified longitudinal vehicle dynamics, powertrain characteristics and engine behavior. This method is also known as backward facing calculation since there is no driver model but how system should behave under certain vehicle speeds over the cycle.

Knowing the losses caused by each system component (vehicle, powertrain and driveline), it is possible to calculate engine torque necessary to keep a certain speed or to accelerate the vehicle. The acceleration may be obtained from speed at consecutive time steps through all analysis cycle.

Equations from the vehicle and engine point of view converge to one tractive force on the wheels. For each time step, the model keeps iterating until the error between tractive force calculated by vehicle and engine equations is lower than an acceptable value.

Since rotational speed has no loss, engine speed is directly calculated from vehicle speed considering dynamic radius from tire and differential and transmission ratios.

One can quickly compare different powertrains using proposed model due to low complexity of inputs and high confidence of variations between compared configurations. This comparison is very important to vehicle development in order to anticipate decision of powertrain selection and avoidance of costly and time consuming tests.

2. MODEL DESCRIPTION

The model is composed by two main components, the vehicle side equations and the engine side equations, as commented hereafter.

2.1 Vehicle side equationing

Starting from vehicle point of view, the speed profile of cycle is known and based on United States Environmental Protection Agency (EPA) cycles Federal Test Procedure (FTP-75), that represents urban part, and Highway Fuel Economy Test (HWFET), that represents highway part of driver profile for fuel economy. The velocity as a function of time for these cycles are shown in Fig. 1, FTP-75, and Fig. 2, HWFET.

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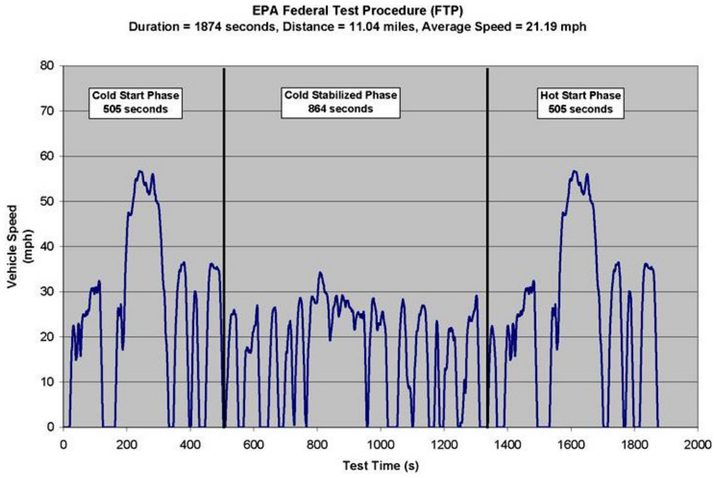

Figure 1. EPA Federal Test Procedure Speed Profile (http://www.epa.gov)

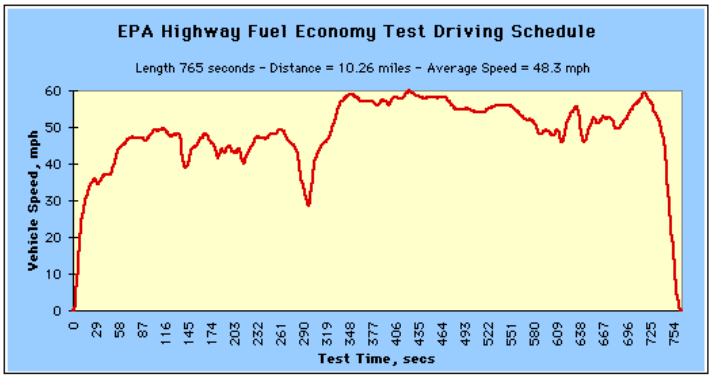

Figure 2. Highway Fuel Economy Test Speed Profile (http://www.epa.gov)

With known speed for each time step, the average acceleration is directly deducted. The mass of the vehicle is an input for the model then leading to Newton's second law that is the starting point from the vehicle side equating.

Resultant force F is the subtraction of all vehicle resistive forces F_{res} (rolling resistance, aerodynamic drag, etc) from the tractive force on the wheel $F_{tractive}$.

Therefore, Eq. (1) summarizes Newton's second law applied to the vehicle.

$$F_{tractive} - F_{res} = m.\left(\frac{v_{t+1} - v_t}{\Delta t}\right) \tag{1}$$

Resistive forces can be written as coast down factors according to Pasquier, Rousseau and Duoba (2001) as they represent all drag, friction and aerodynamic losses of a given vehicle by the Eq.(2). Coast down factors can be obtained by testing procedure that can be found in Society for Automotive Engineers Standard J1263.

$$F_{res} = F_0 + F_1 \cdot v + F_2 \cdot v^2 \tag{2}$$

Where F_0, F_1 and F_2 are the coast down factors and v, the vehicle speed.

Substituting Eq. (2) on Eq. (1) and rearranging in order to isolate the tractive force, one obtain Eq. (3), so that the tractive force can be calculated with known inputs for each time step.

$$F_{tractive} = m.\left(\frac{v_{t+1} - v_t}{\Delta t}\right) + F_0 + F_1 \cdot v_t + F_2 \cdot v_t^{\,2} \tag{3}$$

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2.2 Engine side equationing

The traction force is defined as the driving force acting at the tire treads of the driven wheels (Wallentowitz, 2004), which leads to the Eq. (4).

$$F_{tractive} = \frac{T_{wheel}}{r_{dyn}} \tag{4}$$

Where T_{wheel} is the torque available at all drive wheels and r_{dyn} is the dynamic radius of wheel plus tire.
The torque at wheels is directly related to torque generated by engine through transmission multiplication and losses so the Eq.(4) can be written as Eq.(5).

$$F_{tractive} = \frac{\left(T_{engine} \cdot i_{gear} \cdot i_{diff}\right) - T_{trans.loss}}{r_{dyn}} \tag{5}$$

As commonly the engines are measured without accessories (e.g. hydraulic power steering pump, air conditioning pump), a torque considering this additional losses is also considered.

$$F_{tractive} = \frac{\left[\left(T_{engine} - T_{acc}\right) \cdot i_{gear} \cdot i_{diff}\right] - T_{trans.loss}}{r_{dyn}} \tag{7}$$

With same relation as torque, engine speed can be calculated based on wheel speed. Considering perimeter of the wheel plus tire based on the dynamic radius, the engine speed can also be directly obtained by vehicle speed as stated by Wallentowitz (2004).

$$n_{engine} = \frac{v_t \cdot i_{gear} \cdot i_{diff}}{2 \cdot \pi \cdot r_{dyn}} \tag{8}$$

2.3 Fuel consumption calculation

To find fuel used on each time step one needs two information to access the data from engine measured table: engine speed and engine torque. The drive cycle is defined by vehicle speed along time so a direct relation between these two engine dimensions and vehicle speed is needed.
According to equation (8), engine speed is already directly related to vehicle speed. But engine torque needs to be connected through tractive force. Substituting tractive force from equation (7) in equation (4) and isolating engine torque, the following equation is obtained:

$$T_{engine} = \frac{\left\{\left[m.\left(\frac{v_{t+1} - v_t}{\Delta t}\right) + F_0 + F_1 \cdot v_t + F_2 \cdot v_t^{\,2}\right] \cdot r_{dyn}\right\} - T_{trans.loss}}{i_{gear} \cdot i_{diff}} + T_{acc} \tag{9}$$

Summing all fuel consumed on all time steps divided by its density, the fuel volume consumed on the whole cycle is obtained. Then the average fuel consumption can be calculated by simply dividing the known distance of the cycle by the fuel volume. Average fuel consumption for EPA cycles are normally expressed as *mpg* (miles per gallon) or *km/l* (kilometers per liter).

3. RESULTS

A measurement of a given vehicle under highway cycle (HWFET) was used to check model correlation and error generated by simplification of longitudinal vehicle dynamics. Vehicle characteristics are on Tab(1).

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Table 1. Vehicle characteristics

Vehicle A	
Inertia Weight Class	1134 kg
Engine Displacement	1.0 l
Transmission	Manual 5 speed
Dynamic Radius	0.297 m
Idle Engine Speed	750 rpm
1st Gear Ratio	4.27:1
2nd Gear Ratio	2.35:1
3rd Gear Ratio	1.48:1
4th Gear Ratio	1.05:1
5th Gear Ratio	0.80:1
Differential Ratio	4.87:1

Other main contributors for differences between simulation and vehicle test are the inputs of engine map and coast down factors. For both, it is not guaranteed that same vehicle and engine was used to obtain input data and test vehicle under HWFET cycle. Therefore results deviation is subjected to manufacturing tolerances.

Considering all of above, results obtained are acceptable and presented very good correlation with measured vehicle achieving a difference of 0.8% in full cycle fuel consumption.

The good correlation over the cycle can be checked with two variables calculated on simulation model: engine speed and accumulated fuel volume. Both curves are shown on the graphs of Fig(3) and (4).

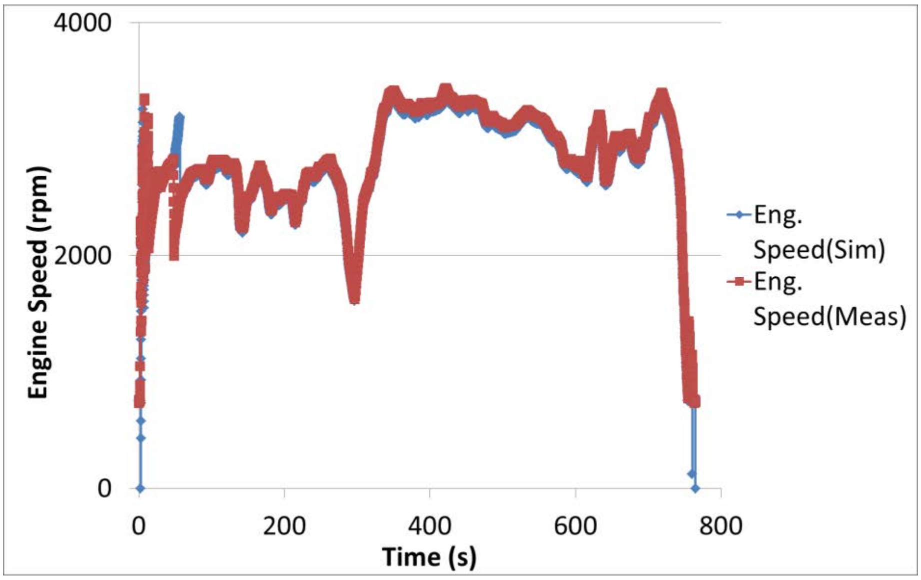

Figure 3. Engine speed comparison

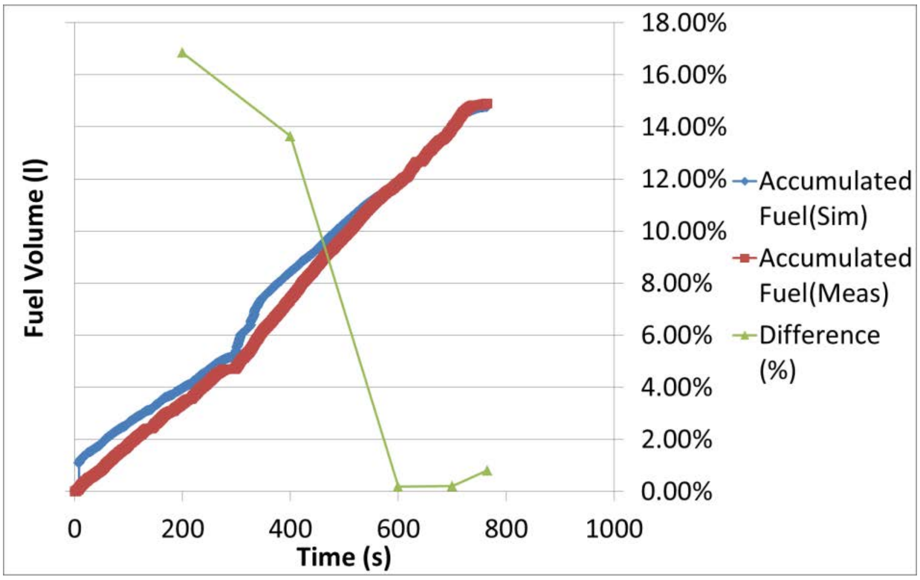

Figure 4. Accumulated fuel volume comparison

4. CONCLUSIONS

Based on these comparisons of engine speed and accumulated fuel volume, the model is considered representative of correlated test.

Even with little dispersion, the fuel consumption profile over time from simulated vehicle is comparable to measured vehicle. This level of fuel consumption estimation makes possible to predict also on which parts of the cycle the vehicle is worst and act in advance to improve the vehicle project.

With fuel consumption profile and normalized fuel consumption in kilometer per liter, one can easily compare different powertrains, different speeds for gear shifting and possible flaws of vehicle (e.g.: high vehicle resistant force and high fuel consumption regions)

As the model shows good correlation, it is possible to select best powertrain possible beforehand avoiding repetition of time consuming and costly tests on vehicle dynamometer.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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7. RESPONSIBILITY NOTICE

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