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Experimental testing and simulations of speed variations impact on fuel consumption of conventional gasoline passenger cars

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ABSTRACT

Speed variations are considered as an alternative for reducing fuel consumption during the use phase of passenger cars. It explores vehicle engine operating zones with lower fuel consumption, thus making possible a reduction in fuel consumption when compared to constant speed operation. In this paper, we present an evaluation of two conditions of speed variations: 50–70 km/h and 90–110 km/h using numerical simulations and controlled tests. The controlled tests performed on a test track by a professional pilot show that a reduction in fuel consumption is achievable with a conventional gasoline passenger car, with no adaptations for realizing speed variations. Numerical simulations based on a backward quasi-static powertrain model are used to evaluate the potential of speed variations for reducing fuel consumption in other speed variation conditions. When deceleration is performed with gear in neutral position, simulations show that speed variations are always correlated to a lower fuel consumption. This was suspected through previous numerical tests or evaluation on test bench but not in controlled tests conditions.

1. Introduction

Different approaches for reducing fuel consumption of passenger cars are currently under development, using vehicle technology changes such as vehicle weight reduction, improvements in aerodynamics and rolling resistance characteristics, or engine modifications, with engine downsizing or electrification of the powertrain (Chan, 2007; Fontaras and Samaras, 2010). There are also strategies that reduce fuel consumption without the need for these technological changes in the vehicle, using changes in driver behavior (Barkenbus, 2010) or in the infrastructure (Chupin et al., 2010; Coiret et al., 2012) to produce fuel consumption reductions.

Vehicle speed variations can be used to reduce fuel consumption. It has been used by trains to reduce energy consumption, allowing the energy recovery during braking events (Nature, 1932). Electric vehicles also have regenerative braking systems allowing the battery to recover some energy during braking phases (Sovran and Blaser, 2006). Internal combustion engines, however, do not

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have the possibility of recovering energy, but as their energy efficiency depends on the engine operating points, one way of lowering fuel consumption is to use the engine at its best operating points, i.e. the points with better energy efficiency, and to avoid using the engine whenever possible.

Speed variations alternate acceleration and deceleration phases, allowing the internal combustion engine to function in higher load operating zones, with better energy efficiency during the acceleration phases and using only the vehicle resistive forces to stop the vehicle in deceleration phases. This driving strategy was named Pulse and Glide (PnG) (Lee et al., 2009). Nevertheless, having a control system allowing acceleration and deceleration of the vehicle to improve fuel consumption was already described in a previous patent (Avins, 1983). In conventional passenger cars with internal combustion engines, shutting down the engine is not possible, one alternative for deceleration being the "coasting" or "sailing" mode, using the clutch or the neutral gear to disengage the powertrain (Koch-Groeber and Wang, 2014). In this case, the engine operates at idle speed, which consumes fuel, but the forces decelerating the vehicle do not include engine braking forces. To our knowledge, although the announced benefits of Lee et al. (2009) article are significant for fuel consumption reduction in internal combustion engines and hybrid electric vehicles, few other recent research studies explored this field: Koch-Groeber and Wang (2014) proposed the application of the strategy with coasting phases in downhill phases of the route profile, Li and Peng (2012) applied pulse and glide in car following scenarios, in order to minimize fuel consumption, Xu et al. (2015) proposed a near-optimal practical rule for drivers or an automatic control system that allowed applying Pulse and Glide strategy and Xu et al. (2016) studied the application of pulse-and-glide strategy during cruising of parallel hybrid electric vehicles (HEVs) in two conditions: (i) speed variations and fixed and state-of-charge (SOC) and (ii) SOC variations and fixed speed and compared the PnG conditions with constant speed operation.

Our research team became interested in speed variations during a study dealing with biologically inspired design, or biomimetics (Freitas Salgueiredo and Hatchuel, 2016) to find disruptive concepts for reducing greenhouse gases emissions produced during the use phase of passenger cars. During this research, systems in nature that had interesting properties in the field of energy management were studied, and speed variations were found to be an useful mechanism for better managing energy in human runners. Billat et al. (2009) observed that speed variations observed in athletes running a 1500 m race could be related to improving performances, because they reduce the depletion of anaerobic energy stores, available in smaller quantities and related to fatigue phenomena.

The objective of this paper is then to perform a simulated and experimental evaluation in controlled test conditions of this concept of speed variation cycles as inspired by human runners in regards to fuel economy of Internal Combustion Engine Passenger cars.

The remainder of this article is organized as follows: Section 2 presents the vehicle model used in the vehicle simulations and the experimental setup used in controlled-tests conditions, Section 3 presents the results obtained for speed variations in the experimentations and simulations. Section 4 discusses the results obtained both in experimentation and simulations and the paper is concluded in Section 5.

2. Methodology

In order to estimate the effect of speed variations on fuel economy in real conditions, a methodology combining controlled tests on a test track and simulations has been designed. A professional pilot conducted the controlled tests on the test track. This pilot is authorized to drive the experimental vehicles and has a specific training on extreme driving techniques. Performing only experiments would be to be too expensive and would not represent all possible conditions, and simulations are not sufficient, as they require a validation step. Thus, specific experimental use cases, representing real life scenarios have been selected to be performed by a professional driver on a test track and simulations have been performed to complete this experimental validation on other scenarios. The simulation can be seen as an interpolation and extrapolation of experimental results.

The estimation of the fuel consumption benefit or loss obtained when applying speed variations required a comparison between fuel consumption while driving at constant speed and fuel consumption obtained with speed variations.

2.1. Experimental setup

Our tests were made in controlled-test conditions, using an internal combustion engine vehicle without the possibility of turning off the engine in decelerations. Two conditions were tested: a similar speed condition (50–70 km/h) as the one tested by Lee et al. (2009) using vehicle simulations (48–64 km/h). We have also tested another speed condition, 90–110 km/h, in order to evaluate whether fuel consumption reduction was also possible for higher speeds. The selected speed conditions have been tested because they represent standard speed scenarios for urban and interurban roads in France.

The vehicle used for the experimentations is a 2008, petrol engine and 5 gears manual gearbox, Renault Clio 3 Eco 2, whose parameters are detailed in Table 3. The fuel consumption is acquired from the CAN Bus channel with a 80 mm^3 resolution. There are also sensors for capturing the longitudinal speed, engine speed, acceleration pedal position and an inertial navigation system, as illustrated on Fig. 1. These sensors allow the measurement of the vehicle position, instantaneous speed and cumulated distance, together with the cumulated fuel consumption. RTMAPS (© INTEMPORA, France) software is used for the real-data logging. All the tests were conducted by the same driver, under similar weather conditions to ensure tests comparability.

All tests were realized on the Satory test track, in France. The test track used for the experimentations is called the "speed test track" being a 2 km long route (Fig. 2), with altitude and slope profiles indicated in Fig. 3. Even if there is few knowledge about the impact of road slope on fuel consumption when using Pulse and Glide strategy, it is well known that slope has a strong impact on fuel consumption. Specific measures were taken to mitigate the impact of the slope parameter. Firstly, the flattest available straight road has been selected. Then, even if an elevation change can be seen in Fig. 3, the slope is still very small (0.3%). Secondly, each

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