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Potential of energy efficiency technologies in reducing vehicle consumption under type approval and real world conditions

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ABSTRACT

Increasing divergence in fuel consumption and associated carbon dioxide (CO_2) emissions between certification and in-use levels has called for improvements in passenger car type-approval procedure. The procedure used for vehicle certification in the European Union changes in September 2017. The first objective was to explore whether the new procedure will steer vehicle development into new technology options to reduce CO_2. The second one was to assess the impact of identified technology options in reducing fuel consumption. These questions were addressed employing simulations, using commercially available software, and following validation. With the new procedure, consumption is more sensitive to reductions in inertial, rolling and aerodynamic resistances while engine measures need to be effective over a wider operation range to bring measurable benefits. In all cases, the new procedure better reflected real world conditions than the old one. This is expected to close the gap between in use and certification consumption levels. Implementing new technology options results in overall CO_2 reductions for conventional gasoline and diesel cars of 13.9% and 12.7%, respectively. Such rather small improvements make it difficult to reach 2021 targets of 95 gCO_2/km without additional measures.

1. Introduction

The role of Greenhouse Gases (GHG) in climate change has been internationally recognized. The 2015 Paris climate agreement, signed by more than 180 countries, calls for international action to reduce GHG emissions [1]. Specifically, European Union (EU) aims at decreasing CO_2 by at least 40% in 2030 compared to 1990 [2]. Transportation is a significant contributor to GHG emissions [3]. As regards CO_2, which is the major GHG, transport sector is responsible for one quarter of the world's combustion-related emissions [4], with road vehicles being the major contributor [5] within the sector. Monitoring the performance of new vehicles registrations is therefore of paramount importance, in particular as global vehicle ownership is expected to increase in the years to come [6].

Fuel consumption, which is directly linked to vehicle exhaust CO_2 emissions, has been reported considerably and consistently lower during vehicle type approval than observed in actual use. Ntziachristos et al. [7] reported 11% and 16% higher fuel consumption over real world conditions for a sample of 611 gasoline and 313 diesel cars, respectively. A study of a small sample of light duty vehicles revealed an average difference of 25% between in-use and type approval fuel consumption [8]. ICCT [9], by analyzing data from approximately 1 million vehicles since 2001, estimated that average in-use fuel consumption of new passenger cars in 2015 was 42% higher than that reported over the New European Driving Cycle (NEDC), which is the current EU type approval test procedure [10]. Most importantly, this deviation seemed to grow with time [11]. Differences in driving style and pattern between in use and type approval conditions may be responsible for part but not all of the reported deviation in fuel consumption [12]. The NEDC-based procedure failed to incorporate certain aspects of real world driving, such as dynamic driving conditions and road slope effects [13]. Mock et al. [14] reported that the consumption of auxiliaries operating during real driving conditions, especially air-conditioning, are not taken into account in the type approval test. Other parameters, such as not accounting for battery discharge in the NEDC procedure, also contribute in reporting lower than the in-use fuel consumption levels [15].

The development of a new test protocol was therefore identified as a precondition to close the gap between in-use and type

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approval fuel consumption levels [16]. In response, the European Commission decided to replace the NEDC with a new procedure [17]. The EU plans to introduce the World-wide harmonized Light-duty Test Procedure (WLTP) for vehicle certification [18] in September 2017. Tsokolis et al. [19] estimated an overall 11–14% higher fuel consumption in WLTP compared to NEDC by testing a sample of 20 passenger cars. An average impact of 20% was estimated by Tsiakmakis et al. [20] for the whole European fleet. Given that the in-use fuel consumption for late technology vehicles is reported more than 40% higher than in NEDC, WLTP is not expected to be able to fully eliminate the gap between type approval and in-use fuel consumption [21].

The new test procedure may however further accelerate the adoption of vehicle technologies aiming at reducing fuel consumption [22]. A characteristic technology example is vehicle mass reduction using lightweight materials [23]. A study conducted by RWTH [24] presents several technology options that are planned to be utilized to improve efficiency until 2020, including engine operation improvements, vehicle mass reductions and driving resistances reductions (both aerodynamic and rolling ones). A similar study performed by Ricardo-AEA [25] presents similar efficiency improvement technologies and the addition of alternative powertrains such as hybrids, energy storage devices and efficiency improvement of the auxiliary systems. Several of these options already made their way to production vehicles while NEDC was in place and their implementation is expected to further increase in the future, as CO_2 emission targets become more challenging [26].

Despite WLTP may not be able to fully reflect observed in-use consumption levels, having a more reliable procedure in place means that the potential of different vehicle efficiency technology options may be better assessed. However, their actual impact over WLTP is not yet fully known. Moreover, introduction of WLTP may guide manufacturers to follow alternative technology pathways to achieve CO_2 reductions than if NEDC was in place, especially if certain technology options are shown to result to different efficiency gains over the two cycles.

The present study assesses the potential of different efficiency technologies to decrease CO_2 emissions under both certification testing and the real world. The objectives are first to reveal the true benefit of various technologies and second to demonstrate how the certification test procedure may steer the penetration of actual technologies to the fleet. Understanding the latter is important both in order to accurately project the future evolution of CO_2 emissions and, most significantly, avoid repeating cases where benefits are reported under certification but are not manifested under real world operation.

2. Methods

The following sections describe the modelling approach that was carried out in order to assess the impact of different technologies under in-use and type approval conditions. First the vehicles employed as test cases are presented, then a description of the conditions used for the assessment follows and finally the simulated technologies are discussed.

2.1. Vehicle models and simulation platform

The analysis was conducted on two vehicle types corresponding to the most popular car segments in the EU, according to market share. Both vehicles comply with the Euro 5 standard [27], and are taken from the small gasoline (0.8–1.2 l) and the medium diesel (1.4–2.0 l) car segments, which together comprise more than 60% of new passenger car registrations in EU for 2014 [28] and 2015 [29]. Basic specifications of the selected vehicle types are shown in Table 1.

Simulation models for these two vehicle types were developed on AVL CRUISE [30] on the basis of a generalized vehicle simulator (Fig. 1) presented in detail by Tsokolis et al. [31]. It consists of the main mechanical and electrical powertrain components, together with the corresponding connections, controllers and functions, simulating the vehicle's operation.

The initial dimensioning and parameterization for the various components were provided by industrial and literature sources [31]. The simulator, including controls and individual efficiencies, was then calibrated until the calculated fuel consumption and CO_2 levels matched the measured ones for the actual vehicles, tested on the chassis dynamometer. The mean CO_2 prediction error over the NEDC and WLTP was found as 2 g CO_2/km, corresponding to 1.6% of the mean value, with a second by second R-square correlation coefficient higher than 0.9. Detailed information on the testing and the validation procedure is presented by Tsokolis et al. [31].

2.2. Operation conditions

Three different driving patterns were used to assess fuel consumption and CO_2 emissions (Table 2). WLTP is the replacement of NEDC in certification testing and consists of a more dynamic driving profile (WLTC – Worldwide harmonized Light vehicles Test Cycle). There are three variations of the WLTC driving profile depending on the power to mass ratio of the test vehicle [17]. The selected vehicles of the current study, fall in the WLTC class 3, like the majority of modern passenger cars. The test mass and driving resistances used corresponded to the most fuel-intensive vehicle configuration and trim level (so called “WLTP-High”) [32]. The Common Artemis Driving Cycles (CADC) [33] were also used as a real world driving pattern. CADC comprise three individual phases, corresponding to urban, rural, and highway conditions. These were developed on the basis of a large database of real world driving patterns and are characterized by more dynamic conditions than both NEDC and WLTP.

2.3. Efficiency technologies considered

A number of technologies were considered in the simulations (Table 3), on the basis of their current penetration to the market [24]. Technologies that are expected to be implemented in near future vehicles according to Ricardo-AEA [25] were also considered. Three scenarios were built assuming increasing effectiveness and market penetration for each technology. The range of values considered was based on historic trends and engineering judgment of technological potential. The package of technologies in each

Table 1
Vehicle specifications used in the simulations.

Vehicle	Transmission	Emission Standard	Curb mass [kg]	Engine Displacement [cc]	Max Power [kW]	Max Torque [Nm]
Small Gasoline	Manual, 5 Gears	EURO 5	1102	1197	66	160
Medium Diesel	Manual, 6 Gears	EURO 5	1465	1995	120	380