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A technical analysis of model year 2011 US automobile efficiency

Nicholas Lutsey

Institute of Transportation Studies, University of California, One Shields Ave., Davis, CA 95616, USA

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ABSTRACT

This paper investigates the new 2011 automobile fleet to quantify the variation in models' efficiency and underlying technology attributes. This involves analysis of test data to quantify the aerodynamic, rolling resistance, and powertrain efficiency characteristics of each model, as well as analysis to understand relationships between these and vehicle fuel consumption. The findings indicate that while vehicles are about 14% efficient on average, there is wide variation and direct evidence of dramatically improved powertrain efficiency within existing models. Existing gasoline and diesel models demonstrate improved powertrain efficiency by over 25%, hybrid gasoline-electric powertrains by over 50%, fuel cells by a factor of three, and all-electric by a factor of four as compared to the average 2011 vehicle. Advanced aerodynamic and tire rolling resistance technologies are also in evidence.

1. Introduction

Consumers and government programs are demanding increased technical efficiency in new automobiles. Over the past 35 years, vehicle size, performance, and fuel economy have shifted according to new product offerings, the availability of new technology, fuel economy regulations, consumer trends, and fuel prices. In terms of current tends, technology developments and the implementation of standards suggest a much more rapid increase in vehicle efficiency in upcoming years. There are emerging advances in engine valvetrain and injection technologies, turbocharging, increased transmission efficiency, and overall vehicle technologies for aerodynamic, rolling resistance, and mass-reduction improvements. Advanced hybrid technologies offer further efficiency improvements. Based on the deployment of these technologies, average new vehicle fuel economy in the US would increase by about 20% from model year 2011 to meet the 2016 regulations (US Environmental Protection Agency, 2010; US Environmental Protection Agency and National Highway Traffic Safety Administration, 2010), and by another 40% by 2025 (US Environmental Protection Agency and National Highway Traffic Safety Administration, 2011).

2. Technological improvements

The potential improvements from powertrain efficiency are found because of the inefficiencies in the modern automobile's ability to convert chemical fuel energy to motive power to propel the vehicle. Improvements beyond the powertrain efficiency exist because of the ability to reduce the road load requirements from vehicle mass, aerodynamics, and tire rolling resistance. The basic energy flows and losses are generalized in Fig. 1 for standard testing cycles, where all the percentages are based on the original 100% of fuel energy that originally enters the vehicle. The percentages, however, can vary widely under different driving conditions. The flow of energy from the fuel tank to vehicle propulsion involves the pumping of fuel through a fuel delivery system, thermodynamic conversion of chemical to mechanical energy in the cylinders, loss of heat through the exhaust and cooling system, engine auxiliaries, accessories, transmission, and braking systems.

E-mail address: nplutsey@gmail.com

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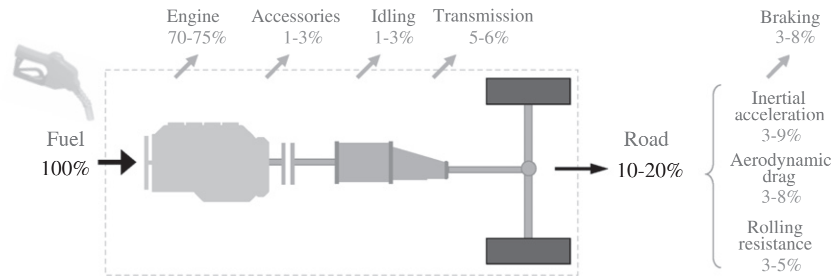

Fig. 1. Illustration of vehicle energy losses.

Typical best values for engine fuel conversion efficiency at their efficient operating points are about 30–40% (Heywood, 1988). By extension, this can represent a rough upper bound for the technical efficiency for combustion vehicles without idling, transmission, and braking losses. The powertrain efficiency, as defined here, involves efficiency from the fueling of the vehicle – through the losses of the engine, engine auxiliaries, accessories, and driveline – to provide tractive force at the wheels to overcome rolling resistance and aerodynamic drag and propel the vehicle. Analysis of vehicle fuel consumption (in units of fuel energy per distance traveled) includes the effects of both powertrain efficiency and road load requirements.

As shown in Fig. 1, accounting for various engine and drivetrain-related losses results in an approximate 10–20% vehicle powertrain efficiency under different conditions. From vehicle simulation modeling, after engine and transmission losses are accounted for, the technical vehicle efficiency is about 12–15% for urban driving, 20–24% for highway driving, and 24–30% in higher speed, aggressive driving (Kromer and Heywood, 2007; Ricardo Inc., 2008). Using a somewhat different accounting method, whereby inertial acceleration is cancelled out, results in average powertrain and braking efficiency values of about 7–9% for urban driving and 25–30% for highway driving for model year 2009 and 2010 vehicles (Hochgraf, 2011; Hochgraf and Duoba, 2010). Several studies have shown how available hybrid models, primarily via regenerative braking, offer substantial increases in efficiency over non-hybrids (Hochgraf and Duoba, 2010).

3. Analytical framework

The analysis has two main components. The first involves the use of US certification data for model year 2011 vehicles (from US Environmental Protection Agency (2011a)) to analyze the powertrain efficiency and vehicle road load factors for aerodynamics and rolling resistance on a model-by-model basis. The second component applies the powertrain efficiency and road load factors to statistical analysis to quantify the contribution of powertrain efficiency, aerodynamics, rolling resistance, mass, and powertrain sizing to vehicle fuel consumption for new 2011 models. Finally, the implications of these results are discussed in the context of future vehicle fleet technology.

The novel contribution of this assessment over previous work is to decompose the effects of powertrain efficiency, aerodynamics, rolling resistance, mass, and powertrain size with a new level of rigor based on empirical certified test data for new vehicle models. In doing so, the study incorporates previously unanalyzed emerging vehicle technologies, employs a methodologically innovative framework to disaggregate powertrain efficiency from physical vehicle characteristics, and statistically isolates the relative effects of powertrain and tractive road load factors on overall vehicle fuel consumption. Improvements from new advanced technologies, including gasoline, diesel, hybrid, electric, and fuel cell models are quantified with hard data, when previously these technologies have been compared only via vehicle simulation modeling with various analytical assumptions. Therefore, this assessment provides a greatly improved snapshot of the technology capability of existing production vehicles, highlighting the variation, potential, and laggards within the fleet. Applying the updated 2011 vehicle characteristics offers new elasticity factors for the contribution of powertrain efficiency, mass, aerodynamics, rolling resistance, and engine size on vehicle fuel consumption.

4. Results

Initially the aerodynamic, rolling resistance, and powertrain efficiency characteristics of 2011 vehicle models are evaluated based on US certification data and known physical automotive engineering relationships. As part of the US regulatory programs for fuel economy and carbon dioxide emissions, US Environmental Protection Agency (EPA) publishes the vehicle model test data that are used for annual certification. This analysis uses the EPA's certification dataset for model year 2011 vehicles (US Environmental Protection Agency, 2011a). This includes city and highway cycle fuel economy data, vehicle test weight, engine size, maximum engine power, transmission, certification fuel, and coast-down coefficients for light-duty automobiles certified for sale in the US.

In terms of filtering the dataset, only city and highway cycles are used, eliminating the more limited data on the other test cycles. Also, duplicate model entries – those with identical identification number, engine, transmission, and test weight – are