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Assessing current vehicle performance and simulating the performance of hydrogen and hybrid cars

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Abstract

A measure of the efficiency in transforming energy input into transport work is defined and applied to road vehicles as well as to sea, air and rail vehicles for passenger or freight transportation. The insight obtained with this measure is compared with the results of applying the conventional measure of kilometres per unit of energy for current fleets of vehicles. Then, simulation methods are used to assess the performance of fuel cell vehicles, electric vehicles and hybrids between the two. The latter are found to provide an optimum performance for a small, efficient passenger car.

Keywords: Vehicle efficiency; Transport work; Hydrogen vehicles; Fuel cell hybrid cars

1. Introduction

The on-the-road performance of passenger cars are often discussed in terms of kilometres driven per MJ (or other unit of energy). This does not do justice to the different payloads that different cars are certified to carry, perhaps considering the poor correlation between required, actually used and available passenger and cargo space characterising the vehicle choice of many passenger car owners. Campaigns have occasionally been directed at increasing customer usage of the available payload (better trip planning, pool arrangements), but automobile sales material often mentions only km/MJ overall performance, if anything at all related to energy efficiency (mentioning energy performance is mandatory in some European countries, but mostly not done in North America). Below, I present performance data in terms of transport work carried out, such as kilometres multiplied by maximum payload that may be obtained per unit of energy input. In addition to being a prerequisite for encouraging better payload utilisation, this also allows transport modes other than passenger cars to be compared on a equal footing. Such comparisons are made for passenger cars, motorcycles, buses, trucks, rail-based trains, ships and aircraft carriers, with payloads that can comprise different ratios between passenger and cargo transportation, as the payload is in all cases expressed in kilograms. This transport work performance measure may be expressed in terms of the maximum certified payload, or it may be expressed in terms of the average actual payload, in order to discuss the role of the payload utilisation fraction (such as seat occupancy for passenger modes).

With the assessment tool described above at hand, a discussion of hydrogen hybrid road vehicles is carried out using simulation techniques. The issue is to determine the optimum battery and fuel cell ratings, with endpoints corresponding to pure electric or pure fuel cell vehicles. The behaviour is non-linear, because the total power requirements for a given driving cycle change as function of vehicle mass, which again—depending on battery type used—is not constant as the ratio between battery and fuel cell ratings are altered. Details of the assumptions will be given in Section 4.

2. Performance of passenger cars

Fig. 1 gives the conventional performance measure for a number of current passenger cars, in km/MJ, but with the

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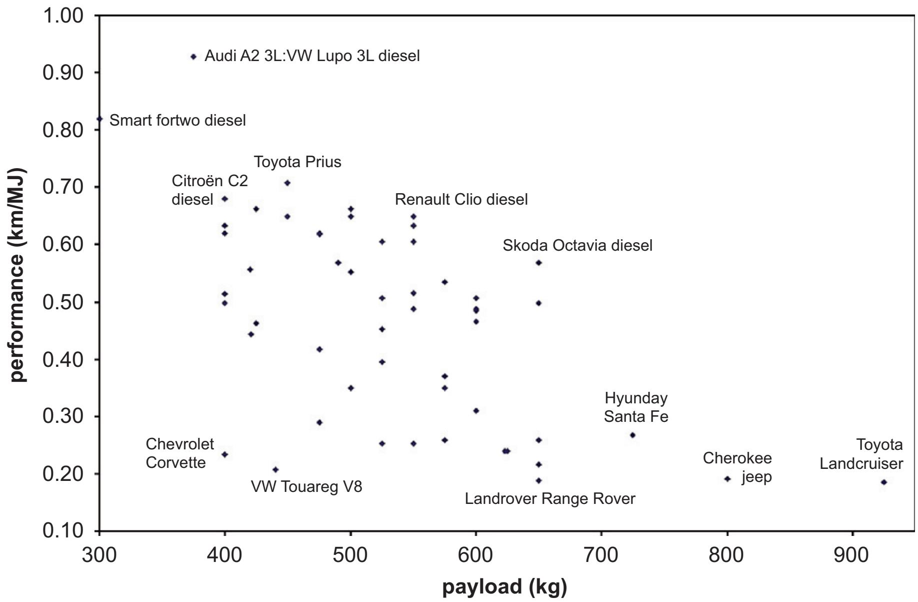

Fig. 1. Conventional passenger car performance measure (km/MJ) for cars on the 2004 Danish market, based on Refs. [1,2] and presented as function of maximum payload.

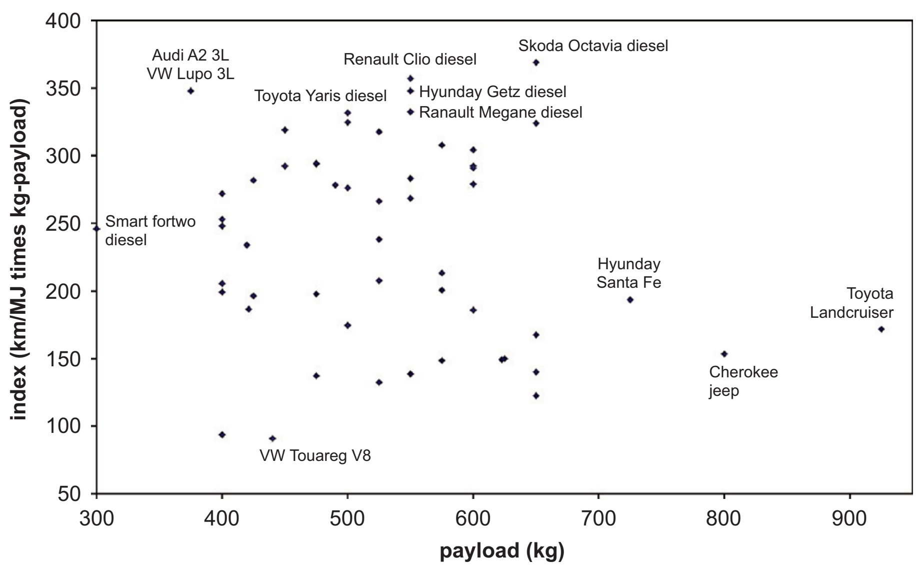

Fig. 2. Transport work performance measure (km/MJ times maximum payload in kg) for cars on the 2004 Danish market, based on Refs. [1,2] and presented as function of maximum payload.

payload mentioned along the abscissa. Payloads are the officially permitted maximum loads provided in the certification documents of each vehicle [1], and the fuel efficiencies are the official test results for the New European Union Driving Cycle, as used for taxation purposes in Europe [2]. One notes the wide spread in performance, indicating that properties other than fuel efficiency are important in consumer choices. The top scoring vehicles are the 1999 Audi A2 and VW Lupo common-rail diesel cars with a proprietary high-efficiency automatic transmission (a computer-controlled, driver-independent gear changing device). These cars are no longer in production, but other cars have emerged over the last 2–4 years, with equally efficient diesel engines (and now with particle filters for greatly reducing environmental impacts) but without the automated gearbox (although with efficiency-optimised gear exchange ratios). This trend started in France (Citroën C2, C3 and their Peugeot counterparts, as well as Renault Clio) but has now been taken up by most automakers outside the USA. Other cars standing out in Fig. 1 are the Toyota Prius gasoline-battery hybrid and the Smart two-seater diesel. At the other end one finds certain sports cars and utility vehicles (4-wheel driven jeeps or tanks constructed for difficult off-road terrain, but often used as