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US Department of Energy Hybrid Electric Vehicle Battery and Fuel Economy Testing

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Abstract

The advanced vehicle testing activity (AVTA), part of the US Department of Energy's FreedomCAR and Vehicle Technologies Program, has conducted testing of advanced technology vehicles since August 1995 in support of the AVTA goal to provide benchmark data for technology modelling, and research and development programs. The AVTA has tested over 200 advanced technology vehicles including full-size electric vehicles, urban electric vehicles, neighborhood electric vehicles, and internal combustion engine vehicles powered by hydrogen. Currently, the AVTA is conducting a significant evaluation of hybrid electric vehicles (HEVs) produced by major automotive manufacturers. The results are posted on the AVTA web page maintained by the Idaho National Laboratory. Through the course of this testing, the fuel economy of HEV fleets has been monitored and analyzed to determine the 'real world' performance of their hybrid energy systems, particularly the battery. The initial fuel economy of these vehicles has typically been less than that determined by the manufacturer and also varies significantly with environmental conditions. Nevertheless, the fuel economy and, therefore, battery performance, has remained stable over the life of a given vehicle (160 000 miles).

Keywords: Fuel economy testing; Hybrid electric vehicle; Performance; US Department of Energy; Envioronmental conditions; Battery capacity

1. Introduction

The advanced vehicle testing activity (AVTA), part of the US Department of Energy's FreedomCAR and Vehicle Technologies Program, has evaluated advanced technology vehicles since August 1995 in support of the AVTA goal to provide benchmark data for technology modelling and for research and development programmes. The AVTA has examined over 200 advanced technology vehicles that include full-size electric vehicles, urban electric vehicles, neighborhood electric vehicles, and internal combustion engine vehicles, powered by hydrogen. Currently, the AVTA is conducting significant investigations of hybrid electric vehicles (HEVs). These include all HEVs produced by major automotive manufacturers and spans over 1.3 million miles. Through the course of this programme, the fuel economy of HEV fleets has been monitored and analyzed to determine the 'real world' performance of their hybrid energy systems, particularly the batteries. The results are posted on the AVTA web page that is maintained by the Idaho National Laboratory [1].

2. Testing

The AVTA uses two HEV testing methods. Baseline performance testing evaluates vehicles by means of a series of detailed procedures [2] on a closed-track and a dynamometer. The schedule typically occurs over a 6-week period, and is performed on new vehicles. Accelerated reliability testing, the second AVTA method, places new HEVs in operating fleets and uses procedural guidance [3] to establish their operating mission and collect data. Each vehicle is operated for as much as 8000 miles per month and data are gathered over its entire service life, which in most cases is 160 000 miles. Typically, two vehicles of a given model are tested: one is subjected to baseline performance testing and both are subjected to accelerated reliability testing.

Baseline performance testing includes assessment of acceleration, range, braking and handling. Two fuel economy trials

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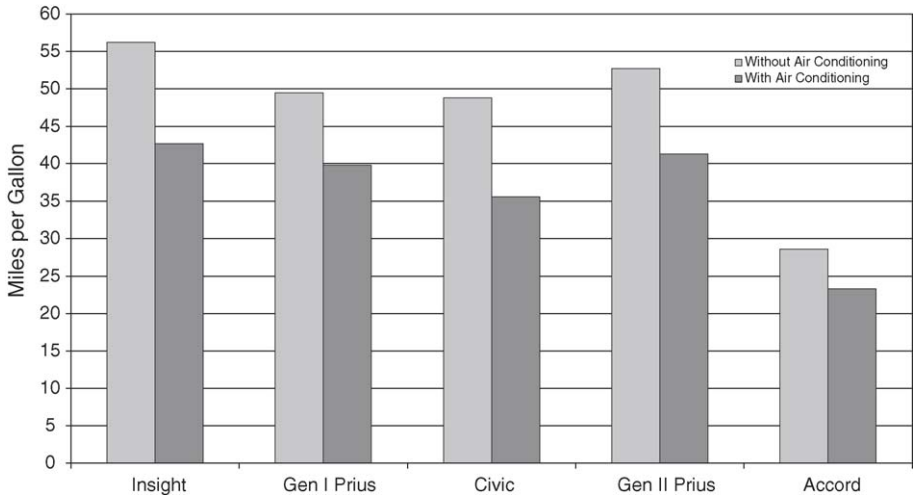

Fig. 1. Baseline performance testing fuel economy with and without air-conditioning operational.

are also conducted in accordance with a detailed test procedure [4] that implements the requirements of the Surface Vehicle Recommended Practice J-1634 of the Society of Automotive Engineers [5]. One trial is conducted with air-conditioning operational, and the other with this auxiliary switched off. After completion of the initial baseline performance testing, vehicles are placed under accelerated reliability testing using fleets in the Phoenix, Arizona metropolitan area. Two vehicles of a model type are typically tested for up to 160 000 miles of combined city and highway driving. At the end of this stage, each vehicle is again subjected to fuel economy testing, as well as to battery capacity and power measurements. As of April 2005, the first-generation Toyota *Prius* (model years 2002 and 2003), Honda *Insight*, and Honda *Civic* HEVs have all completed initial baseline performance testing, accelerated reliability testing, and end-of-life baseline performance testing. The second-generation Toyota *Prius* (model year 2004+), Honda *Accord*, Ford *Escape* and Chevrolet *Silverado* HEVs have completed initial baseline performance testing. These later HEV models have also entered accelerated reliability testing.

3. Baseline performance testing

Comparison of the baseline performance testing results for fuel economy, with and without air-conditioning operational, has revealed a significant decrease in fuel economy with the use of air-conditioning. The fuel economy data for selected HEVs are given in Fig. 1, while the corresponding percentage decreases in this parameter are shown in Fig. 2.

4. Accelerated reliability testing

As of 1 August 2005, the 24 HEVs under AVTA accelerated reliability testing have accumulated 1.35 million miles (Fig. 3) with cumulative fuel economies that range from 18.1 mpg for the Chevrolet *Silverado* to 45.2 mpg for both the second-generation Toyota *Prius* and the Honda *Insight* (Table 1). When viewed on a monthly basis (Fig. 4), the three HEV models (*Civic*, *Insight* and *Gen I Prius*) with the most test miles show seasonal variations in fuel economies of greater than 10% (Fig. 5), and as high as 11.6% for the *Civic*. The 'Hot 3 Months' of summer shown in Fig. 5 are

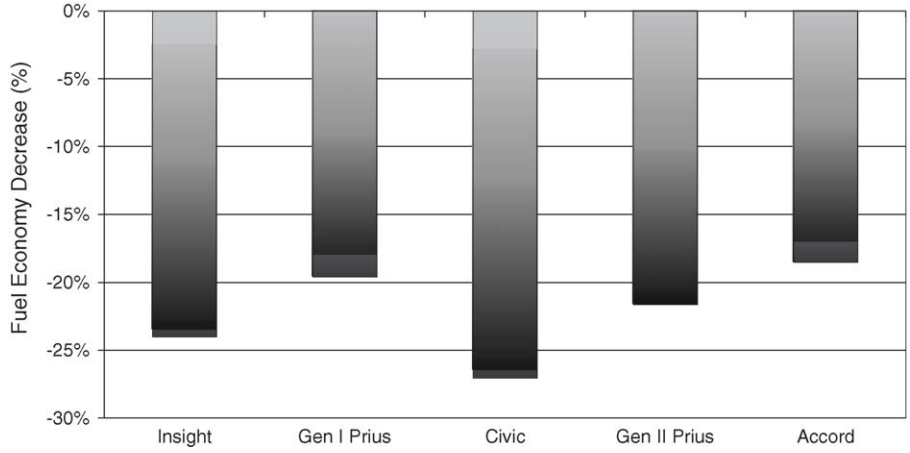

Fig. 2. Percentage decrease in baseline performance testing fuel economy when air-conditioning is operational.

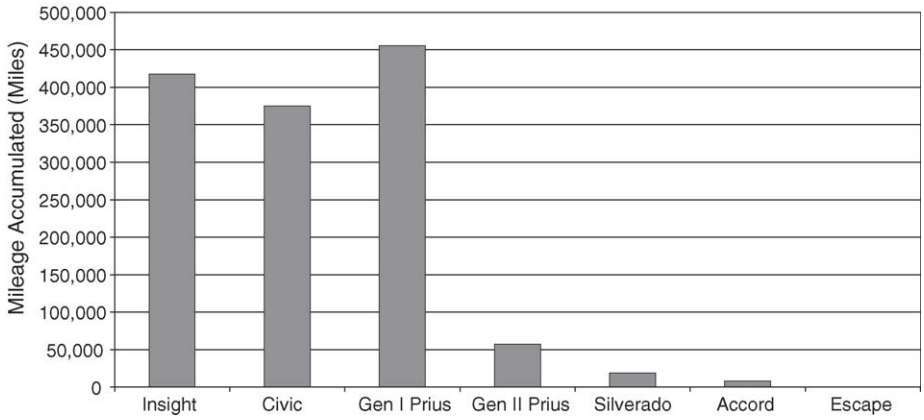

Fig. 3. Total accelerated reliability testing miles by HEV model.

Table 1
Cumulative fuel economy for vehicles under accelerated reliability testing

Vehicles in test	Model and year	Testing status	Cumulative fuel economy (mpg)
6	2001 Honda *Insight*	August 2001–March 2005	45.2
6	2002 Toyota *Prius*	November 2001–March 2005	40.9
4	2003 Honda *Civics*	May 2002–March 2005	37.6
2	2004 Toyota *Prius*	November 2003–ongoing	45.2
2	2004 Chevrolet *Silverado*	September 2004–ongoing	18.1
2	2005 Honda *Accord*	January 2005–ongoing	26.0
2	2005 Ford *Escape*	March 2005–ongoing	NA

June, July and August with average high temperatures of 103 °F and lows of 77 °F. The 'Cool 3 Months' of winter are December, January and February with average high temperatures of 66 °F and lows of 45 °F.

An objective of AVTA testing is to determine the degree of HEV traction battery degradation over the vehicle life. To date, only one traction battery pack has failed during the programme (1.35 million total test miles). A Honda *Insight* with 72 000 miles experienced failure of both the battery control module and the traction battery pack. The two components were replaced by the dealer under warranty. The cause of pack failure is not known. It is speculated, however, that it was caused by failure of the battery control module. To obtain a more precise measure of battery degradation, and its impact on vehicle performance, HEVs completing accelerated reliability testing are envaluated in terms of end-of-life baseline performance fuel economy, battery condition (including capacity testing) and hybrid pulse-power characterization in accordance with the FreedomCar Hybrid Battery Test Manual [6]. The results for fuel economy as completed through to July 2005 are shown in Table 2. Battery testing is currently scheduled for September 2005.

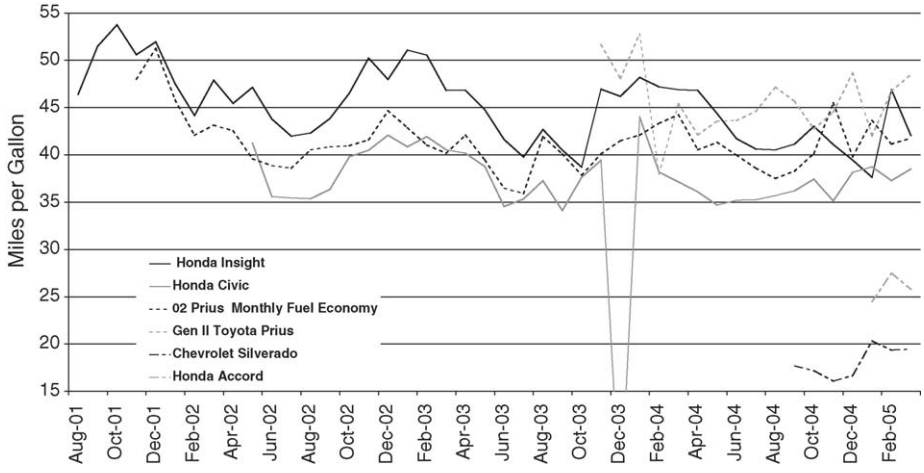

Fig. 4. Accelerated reliability testing fuel economy per month.

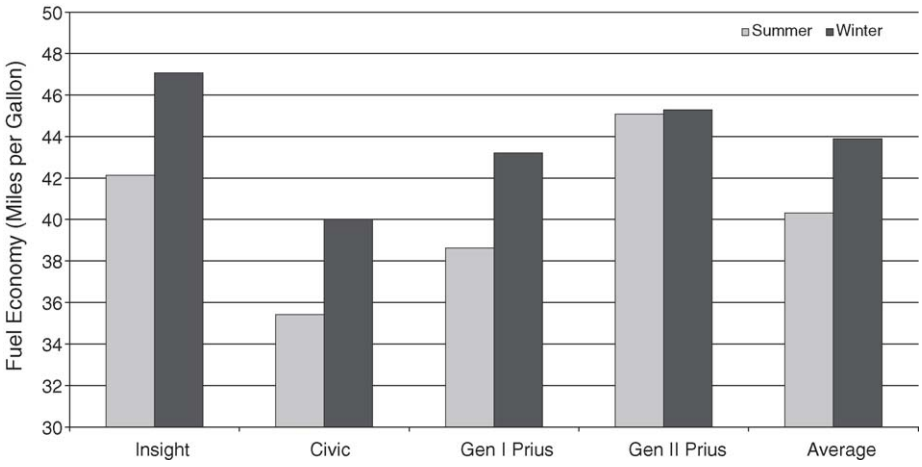

Fig. 5. Seasonal variations in fuel economy for HEVs operating in Arizona.

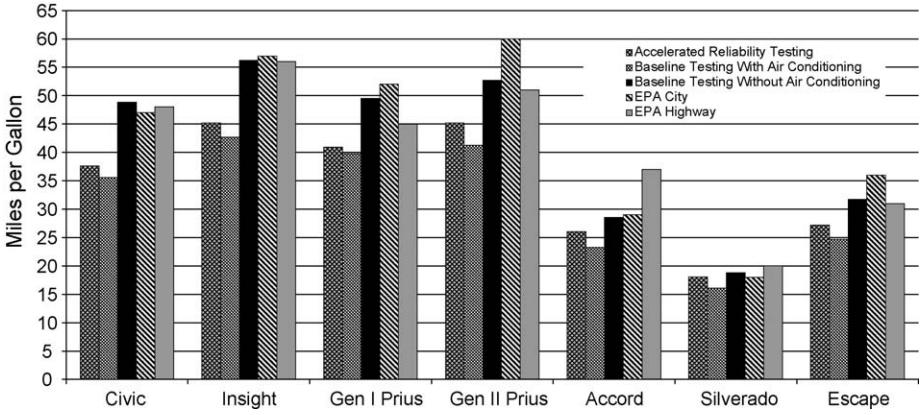

Fig. 6. Fleet and baseline performance fuel economy compared with EPA results.

Table 2
End-of-life fuel economy (A/C = air-conditioning)

HEV vehicle model	Fuel economy			
	New vehicle		After 160 000 miles	
	With A/C	Without A/C	With A/C	Without A/C
Civic	35.6	48.8	36.6	50.1
Gen I Prius	69.8	49.5	40.3	51.7
Insight	42.7	56.2	44.5	55.9

5. Discussion and conclusions

The fuel economy for HEVs operating in 'real world' conditions is found to be less than that predicted by the US Environmental Protection Agency in their rating for new vehicles [7]. As shown in Fig. 6, the baseline performance fuel economy results obtained by AVTA are similar to those of the Environmental Protection Agency (EPA) when testing is conducted in the absence of air-conditioning. By contrast, fuel-economy decreases significantly when air-conditioning is operational. This behaviour is also found with accelerated reliability testing.

Although HEV fuel economy is initially less than that reported by the EPA, it shows little change over vehicle life, as shown in Table 2. This implies that, either battery performance must remain stable, or any decrease in performance must be less than the margin designed into the hybrid energy system. Additional testing will be conducted, including battery capacity and power, to determine the degree, if any, of battery degradation in vehicles that complete accelerated reliability testing. Nevertheless, it is clear from the data collected to date that battery performance is sufficient to provide stable fuel economy over a 160 000 mile HEV life.

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