

# Fuel Consumption Sensitivity of Conventional and Hybrid Electric Light-Duty Gasoline Vehicles to Driving Style

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## ABSTRACT

Aggressive driving is an important topic for many reasons, one of which is higher energy used per unit distance traveled, potentially accompanied by an elevated production of greenhouse gases and other pollutants. Examining a large data set of self-reported fuel economy (FE) values revealed that the dispersion of FE values is quite large and is larger for hybrid electric vehicles (HEVs) than for conventional gasoline vehicles. This occurred despite the fact that the city and highway FE ratings for HEVs are generally much closer in value than for conventional gasoline vehicles. A study was undertaken to better understand this and better quantify the effects of aggressive driving, including reviewing past aggressive driving studies, developing and exercising a new vehicle energy model, and conducting a related experimental investigation. The vehicle energy model focused on the limitations of regenerative braking in combination with varying levels of driving-style aggressiveness to show that this could account for greater FE variation in an HEV compared to a similar conventional vehicle. A closely matched pair of gasoline-fueled sedans, one an HEV and the other having a conventional powertrain, was chosen for both modeling and chassis dynamometer experimental comparisons. Results indicate that the regenerative braking limitations could be a main contributor to the greater HEV FE variation under the range of drive cycles considered. The complete body of results gives insight into the range of fuel use penalties that results from aggressive driving and why the variation can be larger on a percent basis for an HEV compared to a similar conventional vehicle, while the absolute fuel use penalty for aggressive driving is generally larger for conventional vehicles than HEVs.

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## INTRODUCTION

The US Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy and the US Environmental Protection Agency (EPA) jointly maintain a fuel economy (FE) website ([www.fueleconomy.gov](http://www.fueleconomy.gov)), in part to fulfill their responsibility (under the Energy Policy Act of 1992) for providing accurate FE information to consumers. The site provides EPA FE ratings for light-duty cars and trucks from 1984 to the present and information related to energy use such as efficiency-related vehicle technologies, alternative fuels, driving tips, and vehicle maintenance tips. The Oak Ridge National Laboratory (ORNL) conducts studies to validate and improve these tips [1, 2, 3, 4, 5, 6, 7, 8] as part of its contractual obligations to DOE. The main reason for providing information to the public is to increase understanding of vehicle FE issues and to assist consumers in making informed decisions related to their vehicle usage (including driving style), with the goal of lowering energy consumption. One specific goal of this study is to quantify the fuel penalties associated with aggressive driving and subsequently inform the public via the website.

A topic of great interest is fuel use variation with driving style, particularly aggressive driving, which has important implications pertaining to energy consumption, and potential production of greenhouse gases (GHG) and other pollutants. Discouraging high fuel use has global implications and is of interest to a broad audience. Understanding how driving style alters fuel consumption (FC) can have applications which include estimating benefits realized through improved traffic flow in general, and the use of "smart" traffic control systems and autonomous vehicles.

The concept of "aggressive driving" is subjective, and therefore, quantifying the effect of aggressive driving on FC or FE in a meaningful way is problematic. Similarly, "calm" or "normal" driving also is not well-defined. Both calm and aggressive driving can occur over a broad range of circumstances and with a very wide variety of vehicles, giving an enormous "phase space" that could be explored. To address this complex topic, several previous studies were examined, a new vehicle energy model was developed and applied, and a related experimental effort was conducted.

Five previous studies [9, 10, 11, 12, 13] that directly address aggressive driving were reviewed for their relevant content and compared to recent ORNL experimental results to give some general insight on the FC penalty for aggressive driving. Note that each study had different goals and methods, which is not surprising considering the difficulty and broadness of the topic. Only one study included multiple conventional vehicles (gasoline and diesel fueled engine powered vehicles which do not have an electric powertrain and which currently dominate the US market), and one study included several alternative powertrains. All reviewed studies included hybrid technology and at least one conventional powertrain vehicle for comparison. A study quantifying the fuel penalty associated with increasing steady highway speeds [5,14] was also included because driving faster than the posted speed or faster than most of the traffic on motorways or interstate highways can be considered a form of aggressive driving.

Each of the reviewed studies is summarized. These summaries are followed by sections on recent ORNL modeling and experimental efforts. A short section then examines and compares the characteristics of the drive cycles featured in the various studies (with further details in Appendix A) and ways the studies are complementary. This is followed by observations and conclusions targeting the effects of aggressive driving on FE or FC. The results in this paper are generally given in terms of the preferred engineering metric of FC (fuel use per unit distance) rather than FE (such as miles per gallon). Aggressive driving also has safety implications, but safety is not addressed in this paper.

## OBSERVATION OF HYBRID AND CONVENTIONAL VEHICLE FUEL ECONOMY VARIABILITY

Consumers are encouraged to voluntarily submit on-road FE to “My MPG” (

<https://www.fueleconomy.gov/mpg/MPG.do?action=garage>), where these data are collected for both consumer feedback and analysis. These data were examined in a 2011 study by Lin and Greene [15] to compare the self-reported data to the EPA and US Department of Transportation vehicle label FE. Figure 1 summarizes the data graphically. Detailed analysis of the data and the data quality are given in the 2011 study [15] and is not discussed here.

It was observed from the data collected that the dispersion of miles per gallon values for hybrid electric vehicles (HEVs) was larger than that seen for conventional gasoline vehicles. Simple visual observation of the data and statistical analysis verify this. In contrast, most HEVs show much less difference in adjusted (label) FE when the results of the (regulatory) standard EPA city test cycle are compared to the highway test cycle, and multiple examples are given in Table 1. From this observation, one might hypothesize that significantly less mile-per-gallon variation should be experienced with HEVs compared to conventional vehicles. However, consumers drive their own unique and variable drive cycles rather than the

regulatory cycles. In general, the dispersion in FE values is thought to be caused mostly by driving cycle differences (which are influenced by individual driving styles), with other factors such as ambient conditions, use of auxiliary loads, and added vehicle mass also contributing to this dispersion of FE values.

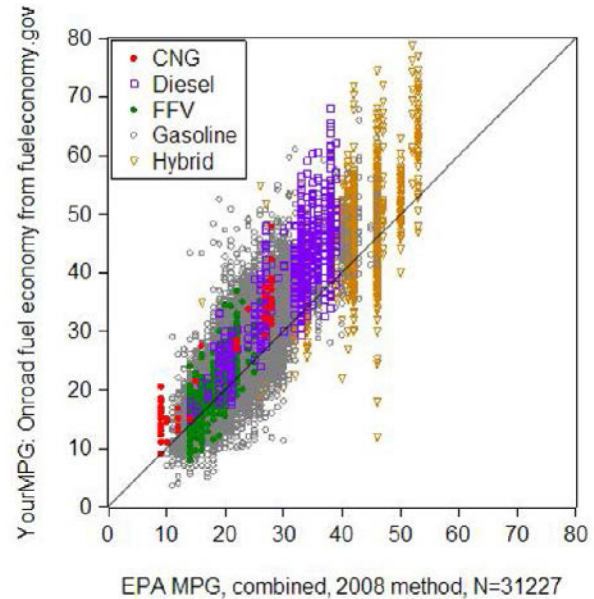


Figure 1. Self-reported miles per gallon (mpg) values from [www.fueleconomy.gov](http://www.fueleconomy.gov) plotted against the EPA label values. CNG = compressed natural gas; FFV = Flexible Fuel Vehicle

Table 1. Label FE values for selected conventional and hybrid sibling vehicles.

| Vehicle models                              | Conventional gasoline | Hybrid gasoline powertrain |
|---------------------------------------------|-----------------------|----------------------------|
|                                             | City/Highway (mpg)    | City/Highway (mpg)         |
| 2015–2016 Ford Fusion                       | 24/36                 | 44/41                      |
| 2012 Hyundai Sonata/Kia Optima              | 24/34                 | 34/39                      |
| 2017 Honda Accord                           | 27/36                 | 49/47                      |
| 2008–2009 Toyota Camry                      | 21/31                 | 33/34                      |
| 2014–2016 Toyota Camry                      | 25/34                 | 40/37                      |
| 2016 Chevrolet Malibu                       | 27/37                 | 47/46                      |
| 2012–2013 Honda Civic                       | 30/39                 | 44/44                      |
| 2014–2015 Nissan Pathfinder                 | 20/27                 | 25/28                      |
| 2008–2010 Highlander, all-wheel drive (AWD) | 17/23                 | 27/25                      |
| 2016 Murano AWD                             | 21/28                 | 26/29                      |

Assuming real-world driving often involves more aggressive acceleration and braking than is captured by the regulatory city and highway cycles, it was hypothesized that HEV FE or FC may be more sensitive to such relatively aggressive driving than conventional vehicles. In the sections that follow previous studies are reviewed, and the results appear to support this hypothesis. It was further hypothesized that in some cases a large contributor to this higher sensitivity stems from the characteristics of regenerative braking (RB) systems [16]. An ORNL study exploring this contention is presented in later sections.

## REVIEW OF AGGRESSIVE DRIVING STUDIES

### European On-Road Study

A relatively ambitious on-road study was performed by Lenaers [9] in Belgium using four similar-size sedans, four levels of driving behavior, and three types of driving routes (a  $4 \times 4 \times 3$  test matrix). Of the four driving behaviors, three were identified as “new,” “relaxed” and “normal.” In some cases all three gave relatively similar FC results, with the normal level most often having the highest FC of the three. The fourth behavior was identified as “aggressive” and resulted in significantly higher FC. To simplify the results, only the relaxed, normal, and aggressive driving styles are compared here. The new driving style featured purposeful shifting patterns to keep engine speed low and in-gear decelerations to cause fuel cut-off, but this strategy only occasionally improved on the relaxed driving style.

### Vehicles

The vehicles were sedans of similar size, listed below. The study did not provide model year information but rather the first year each vehicle was operated (year given in the list) and noted all had low odometer readings. Apart from the Prius, the vehicles were apparently equipped with manual transmissions, as implied in the text of the study (which discusses shifting techniques used for one of the driving styles).

1. Peugeot 307: 1.6 L, 80 kW gasoline engine (2006)
2. Peugeot 307: 1.6 L, 80 kW diesel engine (2006)
3. Seat Leon: 1.6 L, 75 kW engine retrofitted (from gasoline) for liquefied petroleum gas (LPG) and fueled with a mixture of 50% propane and 50% butane (2006)
4. Toyota Prius II: 1.5 L, 57 kW engine; 50 kW electric motor; gasoline hybrid (2005)

### Driving Routes

Three driving routes were examined, named “urban,” “rural,” and “motorway,” with average speeds of 20–26 km/h, 44–50 km/h, and 100–106 km/h, respectively. The driving styles identified as relaxed, normal, and aggressive were characterized as having average acceleration values of 0.45 to 0.65 m/s<sup>2</sup>, 0.65 to 0.80 m/s<sup>2</sup>, and 0.85 to 1.10 m/s<sup>2</sup>, respectively, for the urban and rural routes (not the motorway route). Each vehicle was driven 3 or 4 times for each route and driving style combination. This was described as a small number of repeats, but effort was put into selecting routes and using driving techniques such that driving consistency was achieved. In cases of anomaly due to traffic problems or other reasons, that specific driving test was discarded.

### Fuel Consumption Results

The measured FC increases due to aggressive driving are summarized in [Tables 2 and 3](#). Urban driving showed very high sensitivity to driving style, with a 47%–68% FC increase (ignoring the odd result from the LPG vehicle) comparing aggressive to normal driving styles. The rural route also showed high FC increases for aggressive versus normal driving for the gasoline and diesel vehicles (41% and

46%, respectively) and 18%–19% for the HEV and LPG vehicles. The motorway route tests resulted in modest increases in FC, with 5%–12% increase reported for aggressive versus normal driving styles. The study notes that because traffic rules were obeyed, including speed limits, the level of aggressiveness for the motorway driving was limited.

Table 2. FC comparison for normal and aggressive driving for three driving routes in [9].

| Driving style-route | FC (L/100 km)    |                |              |             |
|---------------------|------------------|----------------|--------------|-------------|
|                     | Gasoline vehicle | Diesel vehicle | Gasoline HEV | LPG vehicle |
| Relaxed urban       | 10.52            | 5.75           | 4.98         | 12.23       |
| Normal urban        | 10.80            | 7.93           | 6.39         | 13.72       |
| Aggressive urban    | 18.13            | 11.63          | 10.15        | 14.96       |
| Relaxed rural       | 6.18             | 4.48           | 4.47         | 8.15        |
| Normal rural        | 6.37             | 4.47           | 4.37         | 8.82        |
| Aggressive rural    | 8.97             | 6.51           | 5.15         | 10.53       |
| Relaxed motorway    | 7.11             | 5.09           | 5.72         | 9.79        |
| Normal motorway     | 7.49             | 5.46           | 5.82         | 9.56        |
| Aggressive motorway | 7.92             | 5.74           | 6.50         | 10.11       |

Table 3. Relative change in FC for normal versus aggressive driving for three driving routes in [9].

| Driving route | FC increase: Aggressive compared to normal driving (%)  |                |              |             |
|---------------|---------------------------------------------------------|----------------|--------------|-------------|
|               | Gasoline vehicle                                        | Diesel vehicle | Gasoline HEV | LPG vehicle |
| Urban         | 67.9                                                    | 46.7           | 58.8         | 9.0         |
| Rural         | 40.8                                                    | 45.6           | 17.8         | 19.4        |
| Motorway      | 5.7                                                     | 5.1            | 11.7         | 5.8         |
| Driving route | FC increase: Aggressive compared to relaxed driving (%) |                |              |             |
|               | Gasoline vehicle                                        | Diesel vehicle | Gasoline HEV | LPG vehicle |
| Urban         | 72.3                                                    | 102.3          | 103.8        | 22.3        |
| Rural         | 45.1                                                    | 45.3           | 15.2         | 29.2        |
| Motorway      | 11.4                                                    | 12.8           | 13.6         | 3.3         |

### 2005. Argonne Six Vehicle Dynamometer Study

An Argonne National Laboratory (Argonne) vehicle research laboratory study using two HEVs and four conventional vehicles was performed using the EPA Urban Dynamometer Driving Schedule (UDDS, also known as the city test) and the Highway Fuel Economy Test (HWFET) cycles and three variants of each cycle using a speed multiplier technique [10]. The primary objective was to quantify FC changes over these cycles, which vary in intensity (speed, acceleration, deceleration), and to show that HEVs respond differently from conventional gasoline vehicles.

### Vehicles

The vehicles listed below were used for the experimental study in [10]. The model years of the vehicles were not specified directly, but the model years could be deduced by the EPA dynamometer target coefficients or other means [11,18] for all except the Honda Insight.



Documents

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Note that vehicle powertrains often remain essentially the same over several model years, so identifying any year within that range is sufficient for FC applications.

1. 2004 Toyota Prius hybrid I4: 1.5 L, 57 kW (76 hp); continuously variable transmission
2. 2000 Honda Insight, I3: 1.0 L, 50 kW (67 hp); 5-speed manual transmission
3. 2004 Ford Focus, I4: 2.0 L; 4-speed automatic transmission
4. 2004 Toyota Echo, I4: 1.5 L, 80 kW (108 hp); 4-speed automatic transmission
5. 2005 Ford Escape V6: 3.0 L, 145 kW; 4-speed automatic transmission; 4-wheel drive
6. 2003 Jaguar XJ8, V8: 4.2 L, 219 kW; 6-speed automatic transmission

### Drive Cycles

UDDS and HWFET cycles were chosen as basic drive cycles in [10]. Four variants of each cycle were defined by simply multiplying the speed by the factors 0.8, 1.0 (the unaltered cycles) 1.2, and 1.4. Figures 2 and 3 offer examples to illustrate the multiplier operation used to define new cycles.

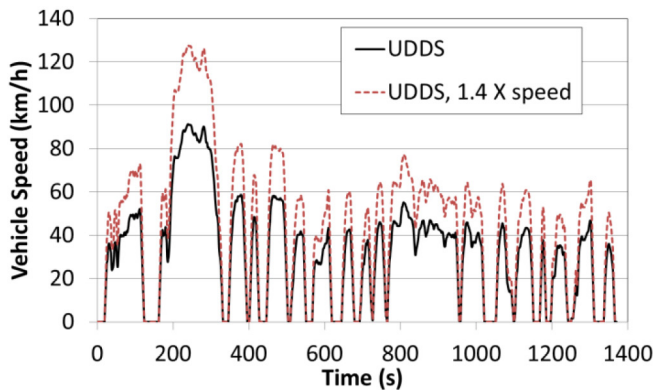


Figure 2. Illustration of applying a 1.4 speed multiplier to the UDDS drive cycle such as in reference [10].

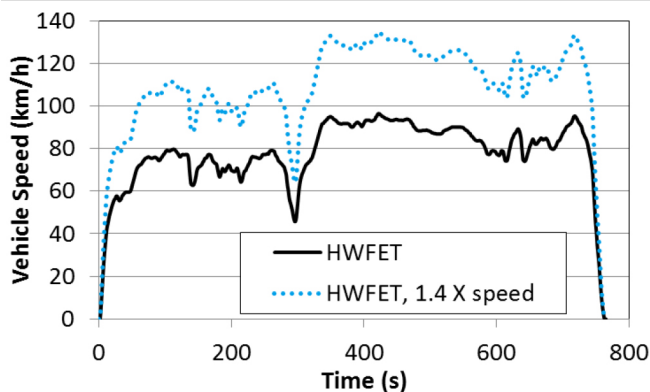


Figure 3. Illustration of applying a 1.4 speed-multiplier to the HWFET drive cycle such as in reference [10].

### Fuel Consumption Results

FC values were determined by chassis dynamometer laboratory experiments in [10]. The UDDS experimental FC results for speed-modified cycles with multipliers of 0.8, 1.0, 1.2, and 1.4 are shown in Figures 4 and 5. The percent change in FC relative to the (unaltered) UDDS and HWFET is given in Tables 4 and 5. The reasoning is these cycles feature relatively moderate to low levels of acceleration and deceleration (see Appendix A) and for the purposes of this study are judged to be most representative of normal or “calm” driving. This is a somewhat arbitrary choice, and the 0.8 multiplier cycles are included for comparison. Values for FC were read from plots using plot digitizing software, and there may be small discrepancies compared to the original data.

The results show that FC generally increases with cycle intensity and indicate HEVs are more sensitive in terms of percent FC change over the range of cycles examined compared to the conventional vehicles. The HWFET-based cycle results show larger FC changes, which are driven mainly by aerodynamic drag. More discussion and explanation of the cycles examined and trends in these data will be presented later.

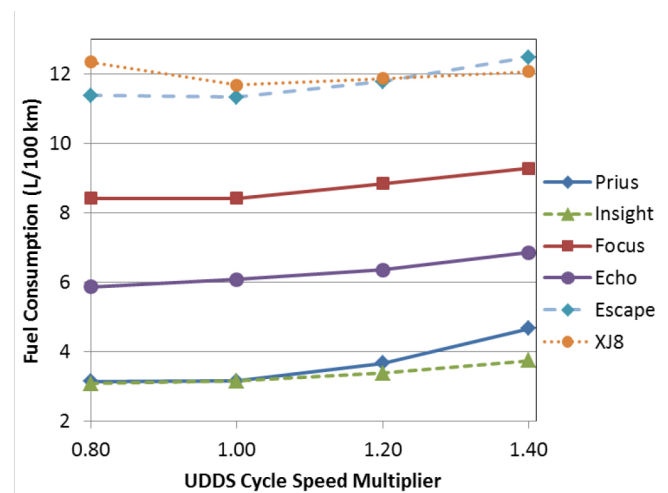


Figure 4. Results for FC for six vehicles tested over the UDDS cycle and intensity variant cycles altered by speed multipliers [10].

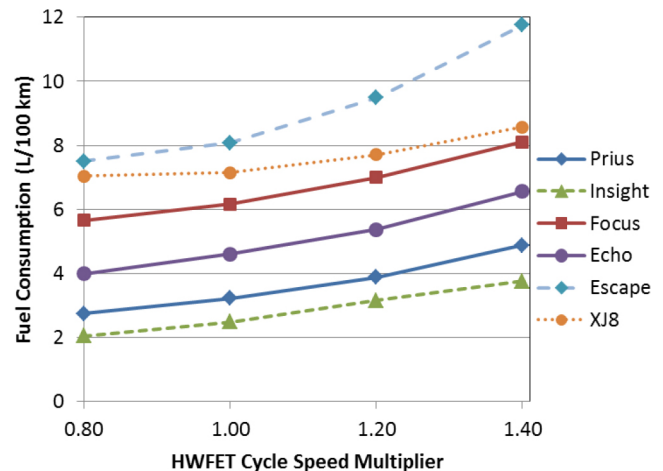


Figure 5. Results for FC for six vehicles tested over the HWFET cycle and intensity variant cycles altered by speed multipliers [10].

Table 4. FC change for six vehicles tested over the UDDS cycle and intensity variant cycles altered by speed multipliers in reference [10].

| UDDS cycle       | Change in FC relative to the unaltered UDDS cycle (%) |         |       |      |        |       |
|------------------|-------------------------------------------------------|---------|-------|------|--------|-------|
| Speed multiplier | Prius                                                 | Insight | Focus | Echo | Escape | XJ8   |
| 0.8              | -0.5                                                  | -2.5    | 0.0   | -3.4 | 0.4    | 5.7   |
| 1.0              | 0.0                                                   | 0.0     | 0.0   | 0.0  | 0.0    | 0.0   |
| 1.2              | 16.0                                                  | 7.0     | 5.1   | 4.7  | 3.9    | 1.6   |
| 1.4              | 47.6                                                  | 18.5    | 10.2  | 12.8 | 10.1   | 3.3   |
| FC (L/100 km)    |                                                       |         |       |      |        |       |
| 0.8              | 3.15                                                  | 3.09    | 8.43  | 5.88 | 11.39  | 12.36 |
| 1.0              | 3.17                                                  | 3.17    | 8.43  | 6.08 | 11.35  | 11.70 |
| 1.2              | 3.67                                                  | 3.39    | 8.86  | 6.37 | 11.79  | 11.89 |
| 1.4              | 4.67                                                  | 3.75    | 9.29  | 6.86 | 12.49  | 12.08 |

Table 5. FC change for six vehicles tested over the HWFET cycle and intensity variant cycles altered by speed multipliers in reference [10].

| HWFET cycle      | Change in FC relative to the unaltered HWFET cycle (%) |         |       |       |        |      |
|------------------|--------------------------------------------------------|---------|-------|-------|--------|------|
| Speed multiplier | Prius                                                  | Insight | Focus | Echo  | Escape | XJ8  |
| 0.8              | -15.0                                                  | -17.6   | -8.1  | -13.3 | -7.0   | -1.5 |
| 1.0              | 0.0                                                    | 0.0     | 0.0   | 0.0   | 0.0    | 0.0  |
| 1.2              | 20.4                                                   | 27.2    | 13.5  | 16.7  | 17.6   | 7.9  |
| 1.4              | 51.2                                                   | 51.2    | 31.6  | 42.7  | 45.7   | 20.0 |
| FC (L/100 km)    |                                                        |         |       |       |        |      |
| 0.8              | 2.74                                                   | 2.04    | 5.66  | 3.99  | 7.51   | 7.03 |
| 1.0              | 3.22                                                   | 2.48    | 6.16  | 4.60  | 8.07   | 7.14 |
| 1.2              | 3.88                                                   | 3.15    | 6.99  | 5.36  | 9.49   | 7.70 |
| 1.4              | 4.87                                                   | 3.75    | 8.11  | 6.56  | 11.76  | 8.57 |

### 2007. Argonne HEV and Conventional Vehicle Study

A subsequent 2007 Argonne study [11] featured experimental results from the study just described [10] for the Prius and the Focus and modeling results for these vehicles using the same cycles and variants. The emphasis of the paper was validation and application of a model. A cycle was added for modeling using a 1.6 speed multiplier, which represents driving at excessive speeds, particularly for the HWFET cycle (128 km/h for the UDDS, 154 km/h for the HWFET), but inclusion may have been useful for model validation. The modeling results were similar to the experimental results already reported in the 2005 study [10].

### 2009. Argonne Plug-In HEV and Conventional Vehicle Experimental Study

A 2009 Argonne study [12] focused on two specialty research plug-in HEVs (PHEVs), noting that PHEVs were not yet available as original equipment vehicles. A Ford Focus was included in the study to allow comparison with a similar size conventional powertrain vehicle.

## Vehicles

The vehicles used in reference [12] are listed below. Note that, for the current purpose of this review, the PHEV data are summarized. However, because the PHEVs were prototype vehicles, they have unknown relevance to today's market.

1. Power-split blended Hymotion Prius PHEV
2. Pre-transmission parallel plug-in hybrid electric, all-electric-capable, test vehicle developed by Argonne; referred to as the Modular Automotive Technology Testbed (MATT)
3. 2004 Ford Focus ZX3: 2.0 L gasoline engine, 4-speed automatic transmission [12,17]

## Drive Cycles

The drive cycles used for comparison were the UDDS and modifications to this cycle to form a number of variants, but in a different manner than in [10]. The UDDS was modified by intensity scaling factors of 1.1, 1.2, 1.3, and 1.4. However, in this case the drive trace vehicle speed was multiplied by the scaling factor and the drive trace time was divided by the same factor. In this way, the resulting cycles have equal driving distance, a speed trace that increases according to the multiplier, and acceleration/deceleration rates that increase in magnitude by the multiplier value squared. For example, using the 1.4 multiplier, vehicle speed is increased by 40%, cycle duration is shortened to 71% (1/1.4), and acceleration increases by a factor of 1.96 (1.4<sup>2</sup>). The baseline UDDS cycle and the cycle intensified by the 1.4 scaling factor are shown in Figure 6.

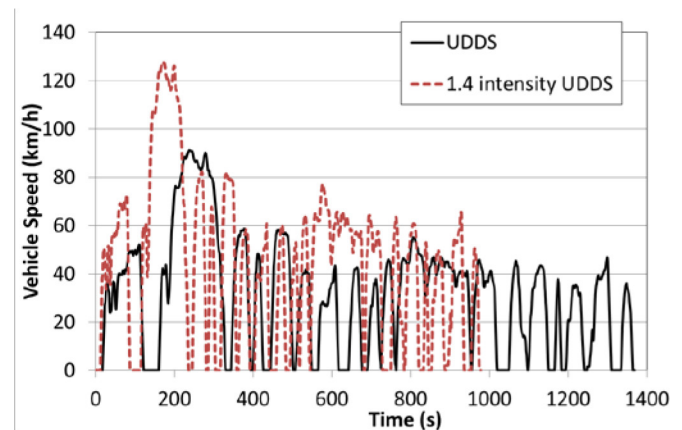


Figure 6. The UDDS drive cycle compared to the same cycle intensified by a 1.4 scaling factor as in [12].

## Fuel Consumption Results

A summary of the most relevant FC results from this study is given in Table 6 [12]. The PHEV vehicle data are for battery charge sustaining mode, and therefore they are operating essentially as HEVs. The Ford Focus data were only collected for the 1.2 and 1.4 intensity multiplier cases, while the other vehicles were operated at cycles derived from all four multipliers. The Ford Focus shows a 34% FC increase for the most aggressive case compared to the UDDS cycle, and the PHEVs show 32% and 89% FC increases. Note again that the FC data were digitized from plots in the publications, which may have introduced small errors.

Table 6. FC and FC change with cycle intensity [12].

| Drive cycle intensity factor | FC increase compared to UDDS cycle (%) |                            |                   |
|------------------------------|----------------------------------------|----------------------------|-------------------|
|                              | Ford Focus                             | Hymotion PHEV Toyota Prius | Argonne MATT PHEV |
| 1.0                          | Baseline                               | Baseline                   | Baseline          |
| 1.1                          |                                        | 7.1                        | 13.3              |
| 1.2                          | 10.6                                   | 9.8                        | 42.4              |
| 1.3                          |                                        | 19.9                       | 52.7              |
| 1.4                          | 33.7                                   | 32.4                       | 89.0              |
|                              | FC (L/100 km)                          |                            |                   |
| 1.0                          | 8.75                                   | 6.53                       | 3.47              |
| 1.1                          |                                        | 6.99                       | 3.94              |
| 1.2                          | 9.67                                   | 7.17                       | 4.95              |
| 1.3                          |                                        | 7.83                       | 5.30              |
| 1.4                          | 11.70                                  | 8.64                       | 6.56              |

### Clemson-ICAR Aggressive Driving Study

A study by the Clemson University International Center for Automotive Research (Clemson-ICAR) examined the effect of driver aggressiveness with the major focus on evaluating the merits of a 48 V mild hybrid system using vehicle modeling methods [13].

### Vehicles

The major attributes of the modeled vehicles in [13] are listed below. The study examined a conventional car and virtually the same car with a 48 V mild hybrid system.

1. Conventional compact car  
Weight: 1,300 kg  
Engine: In-line 4-cylinder, 1.9 L, naturally aspirated  
Transmission: 6-speed manual
2. Compact car with mild hybrid system  
  
Weight: 1,350 kg  
Engine: In-line 4-cylinder, 1.9 L, naturally aspirated  
Transmission: 6-speed manual  
Mild hybrid system: Integrated starter generator and a 48 V, 4.2 Ah lithium ion battery

### Drive Cycles

The Clemson-ICAR study used an actual drive cycle database of more than 1,800 trips to establish criteria for levels of aggressive driving based on the first derivative of acceleration (known as “jerk”) and other factors. The trips were divided into thirds based on the chosen criteria and deemed to be calm, normal, and aggressive driving styles. The trips were then also categorized by length as short (less than 6 km), medium (6 to 12 km), and long (greater than 12 km).

### Fuel Consumption Results

FC estimates in [13] were generated from a modeling effort for the conventional vehicle (Table 7). Aggressive driving compared to calm driving is estimated to add an average of 25% FC for short trips under this study’s scenarios and 22% and 20% for medium and long trips, respectively. Estimated values for FC for the mild hybrid system were not given, but the main fuel savings was attributed to the start-stop system, which is dependent on idle time in the drive cycles. The battery and motor torque assist were estimated to lower FC by about 2%-3% regardless of the driving style. Because FC is reduced in all cases for the mild hybrid vehicle, the hybrid would be expected to be at least slightly more sensitive to driving style, but this hypothesis could not be quantified from the information in the paper.

Table 7. Model-estimated FC values for driving-cycle styles and trip length combinations for a compact conventional gasoline vehicle [13].

|                   | FC, conventional vehicle (l/100 km) |             |           |
|-------------------|-------------------------------------|-------------|-----------|
| Drive cycle style | Short trip                          | Medium trip | Long trip |
| Calm              | 8.26                                | 7.27        | 6.96      |
| Normal            | 9.37                                | 8.12        | 7.70      |
| Aggressive        | 10.35                               | 8.87        | 8.32      |
|                   | FC change (%)                       |             |           |
| Calm              | base                                | base        | base      |
| Normal            | 13.4                                | 11.7        | 10.7      |
| Aggressive        | 25.4                                | 22.1        | 19.6      |

### ORNL Steady Speed Fuel Consumption Study

An ORNL study examined steady speed FE results from chassis dynamometer tests [5,14]. Data sets were collected for 23 vehicles at ORNL’s vehicle research laboratory, and (under a nondisclosure agreement) Chrysler Group, LLC (now Fiat Chrysler Automobiles), provided ORNL with data for another 51 vehicles tested at its Chelsea proving grounds. Combining the two data sets provided a base of 74 vehicles. The data considered are composed of FC for vehicles at steady speeds of 80.5, 96.6, 112.7, and 128.7 km/h (50, 60, 70, and 80 mph) [14].

The results are relevant to this study because driving fast is generally considered a form of aggressive driving. As seen in Table 8, traveling an additional 16.1 km/h (10 mph) faster will increase FC significantly (11%-21% in most cases) for virtually any vehicle, although the amount is vehicle dependent.

Table 8. Change in FC for vehicles traveling at steady speeds of 80.5 km/h and above [14]. Estimates are based on test data for 74 vehicles.

| Speed increase      | Relative FC increase accompanying each 16.1 km/h speed increase (%) |                |                                |
|---------------------|---------------------------------------------------------------------|----------------|--------------------------------|
|                     | Average (%)                                                         | Data range (%) | Middle 75% of vehicle data (%) |
| 80.5 to 96.6 km/h   | 14                                                                  | 7–22           | 11–18                          |
| 96.6 to 112.7 km/h  | 16                                                                  | 10–24          | 12–20                          |
| 112.7 to 128.7 km/h | 18                                                                  | 12–35          | 14–21                          |