COLD-START AND WARM-UP DRIVEABILITY PERFORMANCE OF HYBRID ELECTRIC VEHICLES USING OXYGENATED FUELS: PIGGYBACK PROJECT TO THE VOLATILITY GROUP INTERMEDIATE-TEMPERATURE PROGRAM (CM-138-02)

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Abstract

The Coordinating Research Council (CRC) Volatility Group conducted a program in January and February of 2003 to determine the effect of ethanol content on cold-start and warm-up driveability performance under cool ambient conditions in a large group of late-model vehicles equipped with fuel-injection systems. The goal of the program was to develop concentration-dependent cold-start and warm-up driveability equations for the oxygenate offset of ethanol at cool ambient temperature. The Volatility Group tested 27 conventional vehicles, which were selected from a total fleet of 80 vehicles, based on their response to driveability index (DI) using the highest DI fuel with the highest concentration of ethanol—10 percent.

In addition to these 27 vehicles, the CRC Advanced Vehicle/Fuel/Lubricants (AVFL) Committee requested that the Volatility Group test a small number of hybrid electric vehicles (HEVs) using the same fuels and driveability procedure as the core program. The four hybrid vehicles tested included a Honda Civic, a Toyota Prius, and two Honda Insights.

This paper details the analysis and results of the driveability performance testing from the four HEVs. The paper also includes a description of the four vehicles, the fuels used, the test location, procedures, and conditions. The results from the 27 conventional vehicles used in the core program will be published in a separate CRC report.

The results of the test on the HEVs showed that, as with conventional vehicles, there is a statistically significant effect of fuel ethanol content on the driveability of HEVs. In addition, the three HEV models that were tested each acted differently and had individual idiosyncrasies that need to be taken into account. Whereas conventional vehicles can all be rated in the same manner, hybrid vehicles do not act similarly enough to be able to rate them using the conventional vehicle test method. This finding led to the conclusion that driveability test procedures unique to the evaluation of HEVs should be developed to better understand the impact of fuel variables on the driveability performance of HEVs.

Introduction

Hybrid electric vehicles (HEVs) present a unique opportunity to significantly improve fuel economy and reduce emissions prior to the projected implementation of an alternative fuel infrastructure. Early models have been available in Japan for some time with more recent introductions to the US. Sales have not been significant relative to conventional vehicles but are growing rapidly. In addition, the technology has been developing, with the newer vehicles having substantial improvements over their groundbreaking predecessors. As the US domestic automakers prepare to enter the market, the degree of consumer interest, the breadth of hybrid strategies, and the number of models available all appear to present an alternative market segment with the potential for significant market penetration by early adopters.

In general, HEVs augment power production from the primary powerplant with energy stored in batteries. This stored energy is typically delivered to the drive train, when needed, via an electric machine. The batteries are charged as needed by either the primary powerplant, which in current commercial practice is a small spark ignition engine, or by the vehicle's deceleration energy harnessing, via driveline and wheel braking.

The degree of hybridization runs the gamut from very mild HEVs that essentially power amenities, to strong HEVs with larger battery packs. The stronger HEVs not only launch the vehicle but also provide sufficient power in all maneuvers to allow the internal combustion engine (ICE) to be downsized and generally operated in the optimal part of its speed/load map. A great deal of literature on HEV theory, experiment, and practice is available to those seeking a more complete understanding of the advantages, disadvantages, challenges, and idiosyncrasies of this fascinating class of vehicles (1).

Because HEVs have two energy sources (combustion and battery storage), they might well have both unique driveability characteristics and different responses to fuel composition. Two examples will illustrate the possibilities: idle, and long accelerations. HEVs can be designed to simply turn off when standing at idle. Obviously, there will be no idle roughness in such a system, but if the restart is not instantaneous, the short delay may be rated as a hesitation; hybridization thus has the possibility to remove a source of fuel-related demerits (rough idle) and may also introduce difficulty in rating (the hesitation may not be fuel-related). Long accelerations show how hybrids could in principle be more vulnerable to a new class of fuel related malfunctions not currently tested. A long acceleration may exhaust the capability of the battery pack to assist the ICE. If the ICE has been downsized, the engine will then need to operate at higher load. This may make the engine more vulnerable to enleanment due to low volatility or enleanment caused by oxygenates. If such a condition is possible, the current test procedure may not cause it to occur.

For several years the Coordinating Research Council (CRC) Volatility Group has evaluated the need to test HEVs. Each time the relevant group decided that testing was inappropriate, because production vehicles were either unavailable or at such low volume that fuel response in hybrids was of lesser concern than other fuel/vehicle interactions. In 2002, the Advanced Vehicle/Fuel/Lubricants (AVFL) Committee of CRC, which has the charge to investigate emerging and near future vehicle, fuels, and lubricants, chose to perform an initial investigation to assess the need for a specific hybrid vehicle cycle. To optimize utility, the committee piggybacked four HEVs on the previously planned Volatility group program conducted in January and February of 2003. This program investigated the effect of driveability index (DI) and ethanol concentration on fleet demerits. The results from the Volatility group fleet are available separately (2). An overview of the volatility group program is provided in Appendix A. As will be shown below, this brief, initial look at the interaction between hybrids and fuel composition achieved its goals of determining if such interactions exist, and evaluating the need for a new driveability cycle tailored to the strengths and possible vulnerabilities of HEVs.

Hybrid Electric Vehicles Tested

For this piggyback project four HEVs were used. These vehicles included one Honda Civic, two Honda Insights, and one Toyota Prius. The 2003 Civic rented for use in the project provided the newest production hybrid electric technology of the four vehicles. The mileage on the Civic at the end of the testing was 13,000. One 2000 Insight was provided by ConocoPhillips and had the highest mileage accumulation of all of the HEVs tested (16,600 mi). The National Renewable Energy Laboratory (NREL) loaned an additional 2000 Insight and a 2001 Prius to the project. These two vehicles had the lowest mileage levels of all four of the HEVs, 3200 and 6600 miles, respectively.

The Honda Insight and Toyota Prius were the first two HEVs commercially available in the United States. These two vehicles have some very basic similarities – both combine power from a gasoline engine with an electric motor and a nickel-metal hydride (NiMH) battery pack to provide motive force. The Honda Insight has a smaller pack that consists of 20 modules, each having six D-sized spiral-wound cells (see Figure 1). The total pack nominal voltage is 144 volts (V). The total energy capacity of the Insight pack is 936 watt hours (Wh). The ends of the 20 D-sized modules can be seen in Figure 1. Also shown are the fan and the outside of the ducting that directs cabin air across the modules for cooling. The larger Prius battery pack is a later generation NiMH design that consists of 38 prismatic modules, each having six 1.2 V cells. The total pack nominal voltage is 273.6 V. The total energy capacity is 1778.4 Wh. Figure 2 shows the Prius pack with the 38 prismatic modules as they are arranged in the pack (3).

The Honda Insight is a light-weight (856 kilogram (kg) curb weight), two-passenger hatchback powered by a 50 kilowatt (kW) gasoline engine with additional assist power provided by a 10 kW electric motor. The Insight has a parallel HEV configuration and has manual transmission. The electric motor is coupled directly to the drive shaft of the engine and provides additional power for relatively hard accelerations. It also operates as a generator to recapture kinetic energy during deceleration and helps balance vibrations of the in-line three-cylinder, 1.0-liter engine (4,5).

The Toyota Prius is a five-passenger compact sedan powered by a 52 kW gasoline engine and a 33 kW electric motor. It has a curb weight of 1254 kg. The Prius has a more complex dual-mode hybrid configuration where energy to and from the vehicle wheels can travel along several different pathways. Mechanical energy to the wheels passes through a planetary gear set that couples the engine, electric motor, and generator to the final drive. Power to the wheels can be provided solely by the battery pack through the electric motor, directly from the gasoline engine to the wheels, or from a combination of both the motor and the engine. The battery pack can be recharged directly by energy taken from the wheels through the generator (regenerative braking) or from excess energy from the gasoline engine (also turning the generator) (3). The Prius utilizes an electronically controlled continuously variable transmission (ECVT).

The Honda Civic is the most recent HEV to be released for public sale. The Civic is powered by a gasoline engine with an electric motor and a NiMH battery pack, similar to the Insight, although the four-cylinder, 1.5-liter engine is 50 percent larger. The Civic is a five-passenger compact sedan powered by a 63 kW gasoline engine and a 10 kW electric motor. The Civic is also configured with the continuously variable transmission (CVT). It has a curb weight of 1239 kg. The Civic has a battery pack that consists of 120 cells at 1.2 V each. The total pack nominal voltage is 144 V (6).

Previous testing on the Insight and Prius at NREL provided some information related to the unique performance of these vehicles and their battery packs. NREL's testing of the Honda Insight and Toyota Prius has revealed or quantified the results of a number of design differences that affect battery usage. These differences are due in part to the geometry and design of the packs, but also in large part to the design of the vehicle and control systems. Both vehicles have 6.5 ampere hours (Ah) NiMH battery packs, but the Prius pack is a later-generation prismatic design that is also significantly larger, corresponding to the more intensive use of the car’s electric motor. The Prius’ 33 kW electric motor is used in a wider range of applications including all-electric propulsion under low-load, low-speed conditions.

Testing showed that the Insight limited pack usage to approximately 60% of the rated 6.5 Ah capacity, while the Prius was limited to 40%. The Prius control strategy features a target indicated battery pack state of charge (SOC) of approximately 56%. Use of the battery and electric motor are strongly influenced by this target. The Insight apparently has a much broader range in which the SOC is controlled with no single target SOC. The Prius uses substantially more battery energy over a given driving cycle. For the Prius, the amount of propulsion energy supplied by the battery was nearly 10% of the gasoline fuel energy used by the engine on the Federal Test Procedure (FTP) driving cycle. The highest level of pack energy used by the Insight was 3% of the fuel energy for the SC03 cycle with air conditioning (3). The implications of these differences on the results of this program and impacts on future programs will be discussed in detail in a later section.

Figure 1, Honda Insight Battery Pack

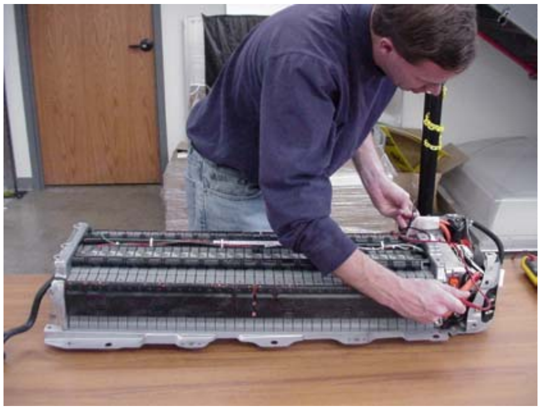

Figure 2, Toyota Prius Battery Pack

Test Fuels

The fuel matrix used for this program consisted of ten fuels; that is, a high DI (1300) hydrocarbon base fuel with a nominal 7-psi vapor pressure and nine different blended test fuels. Three test fuels were prepared by splash blending 3, 6, and 10 volume percent ethanol into the base fuel (E1, E2, and E3). Three hydrocarbon-only test fuels were prepared by adding a light hydrocarbon mixture to the base fuel to roughly match the DIs (10%, 50%, and

90% evaporated points) of the three splash ethanol blends (H1, H2, and H3). The final three fuels were prepared by mixing 3, 6, and 10 volume percent ethanol with hydrocarbon gasoline components to meet a constant 1300 maximum DI limit for all three fuels (E4, E5, and E6). Samples were obtained on-site and shipped to a volunteer's laboratory facility for inspection. These specifications are shown below in Table 1. Indeed, all of the fuel used in this study exhibited a very high DI, with all exceeding the maximum ASTM DI specification of 1250. The occurrence of fuels of this nature in the field are currently rare, but they are occasionally experienced.

Table 1, Test Fuel Specifications

Inspection	Units	Base	E1	E2	E3	H1	H2	H3	E4	E5	E6
API Gravity	°API	53.8	53.7	53.7	53.4	55.2	55.3	55.8	51.8	51.6	50.7
Relative Density	60/60°F	0.7638	0.7638	0.7642	0.7654	0.7578	0.7577	0.7555	0.7721	0.7729	0.7766
DVPE	psi	7.81	8.91	9.02	8.90	8.77	8.81	8.90	7.91	8.00	8.00
Oxygenates--D 4815											
MTBE	vol%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAME	vol%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EtOH	vol%	0.0	3.2	6.1	10.6	0.0	0.0	0.0	3.3	6.0	10.2
O2	wt%	0.0	1.15	2.19	3.83	0.0	0.0	0.0	1.19	2.13	3.64
D 86 Distillation											
IBP	°F	90.6	94.4	94.1	96.4	87.2	89.0	87.6	94.2	99.4	102.0
5% Evaporated	°F	121.0	116.8	118.0	120.5	114.0	115.5	114.8	122.8	124.5	127.7
10% Evaporated	°F	139.1	126.0	128.3	130.1	128.5	131.4	130.1	132.1	134.1	137.8
20% Evaporated	°F	171.9	147.1	143.0	144.9	157.3	160.6	159.2	155.6	146.9	151.4
30% Evaporated	°F	206.3	192.4	161.3	155.7	192.3	193.0	189.6	202.9	176.3	159.7
40% Evaporated	°F	231.7	226.8	219.8	171.7	224.5	223.4	216.6	232.6	226.1	212.1
50% Evaporated	°F	248.0	244.8	242.8	236.6	244.4	244.5	238.0	250.3	246.3	249.4
60% Evaporated	°F	265.6	262.5	260.3	256.0	264.1	265.7	261.2	271.5	269.9	268.5
70% Evaporated	°F	297.2	292.3	288.8	283.1	296.1	297.3	297.1	280.3	304.4	303.8
80% Evaporated	°F	327.2	325.4	324.5	322.1	325.7	326.1	325.0	332.0	331.4	331.8
90% Evaporated	°F	343.4	342.9	342.3	341.6	341.0	340.3	337.9	346.4	347.2	346.6
95% Evaporated	°F	357.2	356.4	356.2	355.5	353.9	351.9	348.6	361.0	361.5	360.4
EP	°F	386.3	380.7	384.9	382.4	383.0	379.9	376.6	390.8	390.9	386.2
Recovery	vol%	97.9	97.7	97.5	97.8	98.0	97.5	97.6	98.1	98.0	97.9
Residue	vol%	0.9	1.0	1.1	1.0	0.9	1.1	0.9	0.9	0.8	1.0
Loss	vol%	1.2	1.3	1.4	1.2	1.1	1.4	1.5	1.0	1.2	1.0
Percent Evaporated at 158°F	vol%	15.9	22.7	29.2	32.2	20.0	19.2	19.8	20.7	24.6	29.4
Percent Evaporated at 200°F	vol%	28.0	32.1	36.6	44.4	32.3	32.1	33.8	29.4	34.7	37.7
Percent Evaporated at 250°F	vol%	51.3	53.4	54.6	56.4	53.5	53.0	55.5	50.0	52.0	50.2
Percent Evaporated at 300°F	vol%	71.1	72.2	73.3	74.3	71.6	71.0	71.0	74.1	68.7	69.1
Driveability Index		1295.9	1266.4	1263.3	1246.6	1267.1	1270.9	1247.0	1295.4	1287.2	1301.4

Test Location

The test program was conducted at the Renegade Raceways near Yakima, Washington in the valley of the Yakima River at an altitude of 990 feet. The test site was a 0.7-mile long, 60-foot wide, flat, paved, two-lane drag strip, along with several adjacent single-lane, paved, auxiliary roads normally used for racecar preparation. A large, rectangular, paved area suitable for defueling/refueling and vehicle storage also was utilized. The race staging area at the base of the track was used for soaking the vehicles overnight.

Test Procedure

The test fuels were evaluated as prescribed in the CRC Cold-Start and Warm-up Driveability Procedure (E-28-94). Duplicate tests were performed on every vehicle and fuel combination.

The CRC Cold-Start and Warm-up Driveability Procedure consists of a series of light, moderate, and wide-open-throttle maneuvers mixed in with idles to obtain as many evaluations of driveability in a cold engine as possible. Figure 3 shows one of the Insights during an acceleration maneuver at the Renegade Raceway. Malfunctions are evaluated and recorded as being trace, moderate, heavy, or extreme. The absence of malfunctions was recorded as clear or clean. The driveability test procedure and demerit rating details used in this program are shown in Appendix B. During set-up week, the raters were provided with all the test vehicles to set individual vehicle vacuum targets and, more importantly, to allow them to agree on a similar definition of malfunction severity.

Figure 3, Insight During Acceleration Maneuver

All vehicles were tested each day using three raters and three observers who recorded the ratings, with a specific rater assigned to exclusively test the same vehicles for the entire program. Three raters were used throughout the program. Each vehicle was assigned its own fuel each day.

The three rating teams tested the fleet of 31 vehicles in three hours. Generally, three vehicles were on the track simultaneously, separated by approximately 0.3 miles. Overtaking a severely malfunctioning or stalled vehicle was accomplished in a safe predetermined manner. No problems with vehicles impeding one another were encountered using this schedule, even though stalls and severe malfunctions did occur.

Test Conditions

Temperatures at this location were stable for around three to four hours bracketing dawn. The overnight soak temperatures ranged from 22° F to 37° F (with the exception of one night at 15°F). The mean soak temperature was 31.9° F. All tests were carried out in the test-temperature range of 30° F to 42° F and 97.3 percent of the tests for all the 31 vehicles fell inside the planned temperature window of 30° F to 40° F. The mean test-temperature was 37.0° F.

Results

The results presented in this paper are divided into two sections: One section focuses on the analytical results, while the second section discusses the subjective information gained from the program. Since all of the information reported in this section is limited to a small amount of data collected from only four HEVs, these results should not necessarily be applied to all HEVs.

Analytical Analysis

Two data points were obtained for all four HEVs on each of the 10 fuels for a total of 80 tests. The diligent efforts of the field team produced data in a well-controlled temperature range, despite the fact the hybrids were the last vehicles tested each day. If there was any danger of exceeding the specified temperature range for the primary test fleet, the tests were postponed to the following day. All tests were conducted in a run-temperature window of 30°F to 42°F inclusive. The complete date set used for the following analysis is located in Appendix C.

Rater and vehicle are confounded in this analysis because each vehicle was assigned to a rater. Thus, any statements about rater or vehicle alone are unsupported; the variable car will present the combined effect. Car was treated as a class variable in all the analyses, while all the other variables were centered and treated numerically in the analysis. The SAS system for windows release 8.02 was used for the analysis (7).

First, the normality of the data was appraised using the SAS procedure proc Univariate. The data were reasonably normal (minimum 8, mean 60, maximum 164, and standard deviation 36.8) but skewed (skewness=0.84), and the variance increased with magnitude. In order to more closely approximate the assumptions of normal statistics, the transform Y=Ln(Total Weighted Demerits (TWD) +1) was used. This improved the normality of the dependent variable. The mean of the transform was 3.91 relative to a minimum and maximum of 2.2 and 5.1, with a standard deviation of 0.68, and a skewness of -0.44.(see Appendix D)

Having established a normal dataset, the analysis was conducted on centered variables using proc GLM. All nonsignificant variables were dropped. The effects that remained were car, soak, ethanol, and DI, plus an intercept. Car, DI, and the intercept were significant at alpha=0.0001 (99.99% confidence), while ethanol and soak temperature were significant at alpha =0.014 and 0.044, respectively. The coefficients are provided in Table 2, below.

Table 2, Regression Statistics

		Standard		
Parameter	Estimate	Error	t Value	Pr > |t|
intercept	-0.857108113 B	0.08646489	-9.91	<.0001
Car 84	1.150603940 B	0.12228066	9.41	<.0001
Car 85	1.116298275 B	0.12227970	9.13	<.0001
Car 86	1.161530238 B	0.12227970	9.50	<.0001
Car 87	0.000000000 B			
DI	0.010832567	0.00229222	4.73	<.0001
ethanol	0.028083738	0.01110476	2.53	0.0136
soak	-0.019839109	0.00968464	-2.05	0.0441

Car is a class variable that represents the contribution of the car/driver combination, DI is a continuous variable representing the driveability index in degrees F, ethanol is a continuous variable representing the percent ethanol, and soak is a continuous variable representing the overnight minimum temperature in degrees F. The "B" following some of the estimates indicates that the result is referenced to a specific class level being set arbitrarily to zero. In this case, all the other car/rater combinations are referenced to car/rater 87. The intercept is also referenced to this value. This process is common when class variables are used. It cannot be over emphasized that the results and significance levels apply to this fleet in this test, not to all HEVs.

The overall regression has an F value of 28.05 and a probability of higher F of <0.0001. Car rater combinations 84, 85, and 86 were all significantly different from car/rater combination 87 (see Table 2), but were not significantly different from each other (90% confidence level).

Least squares (LS) means (a best estimate of the mean taking all other factors into account) were calculated for each vehicle and in a separate regression with fuel as a class variable for each fuel. The results are presented graphically below in Figures 4 and 5. The six splash blended fuels were not significant from each other, (90% confidence level) overall regression F=15.3, Pr>F <.0001. The lower match blends were not different from the base fuel, but the highest blend (fuel E6 in Figure 4) was different (90% confidence level) overall regression F=15.3, Pr>F <.0001. The two higher ethanol content match blends were significantly different from all splash blends (98 to 99.99% confidence level), but the lowest match blend was generally not different from the splash blends (90% confidence level overall regression F=15.3, Pr>F <.0001). The two Insights and Prius were not significantly different (90% confidence level), but were different from the Civic (99.99 confidence level overall regression F=28.05, Pr>F <.0001) see Figure 5.

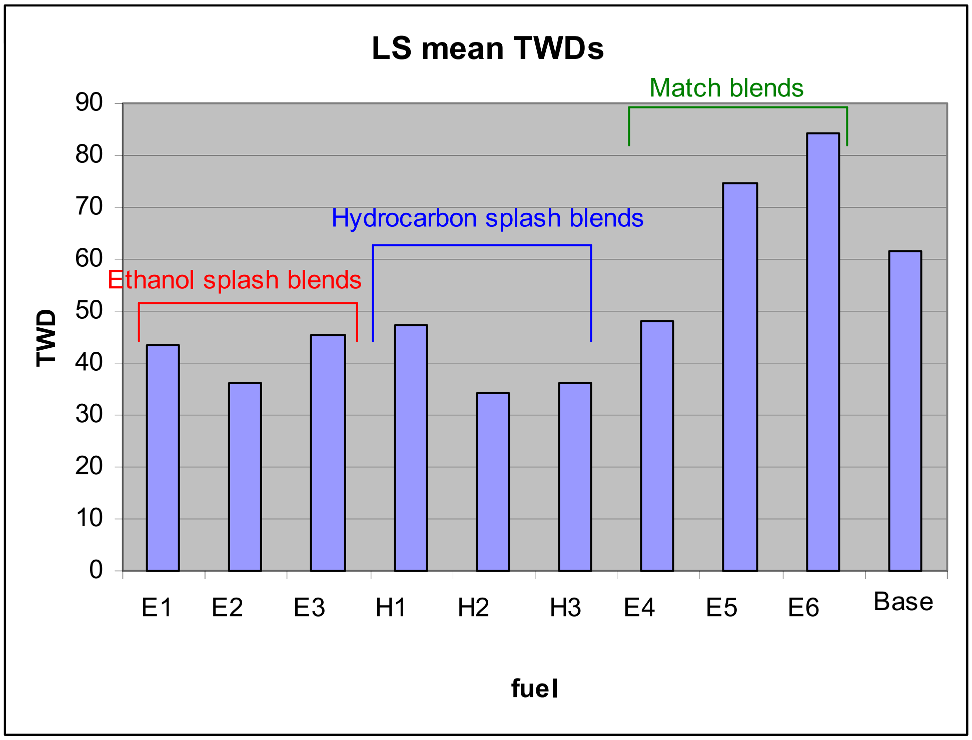

Figure 4, HEV Driveability Fuel Dependent Results

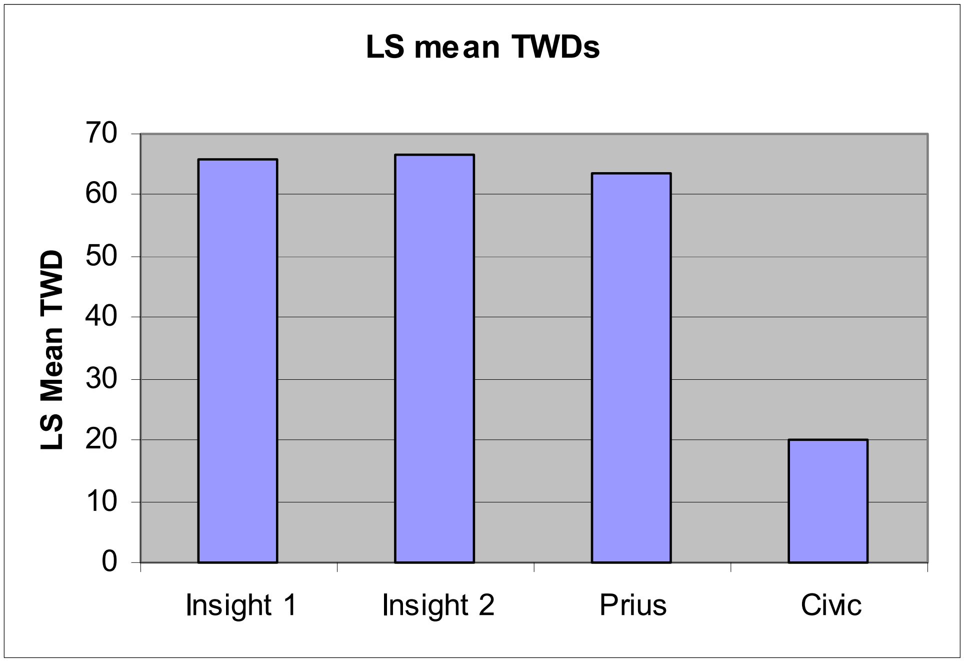

Figure 5, HEV Driveability Test Demerit Results

Subjective analysis

The three hybrid models each act differently and have individual idiosyncrasies, which must be taken into account. Whereas conventional vehicles can all be rated in the same manner, hybrid vehicles do not act similarly enough to be able to rate them all in the same manner with the current test.

The first obvious challenge is that the CRC Driveability Procedure was developed for automatic transmissions; however, the two Insights were equipped with manual transmissions. One rater was assigned both Insights in this program in an attempt to omit the shifting variability inherent among drivers. The rater determined the shift points for each maneuver before the test program began. The rater determining the shift points attempted to simulate the shift points of an automatic transmission so that the transition between gears was as natural as possible. Different shift points may be necessary for different models. Also, there is only one idle rating applicable during the starting procedure; there is no "Drive" idle rating. The detent maneuver is not applicable for manual transmissions either; detent was performed at wide-open-throttle in second gear.

The Insights also have an idiosyncrasy in their start times. Several times they would quit cranking before the normal five seconds allowed. The rater would still have the key in the crank position, but they would stop cranking on their own. The rater would then release the key, turn the key off and on again to re-pressurize the fuel rail, and begin cranking again, and the same thing might or might not happen. These were recorded in the database as no-starts, although a conventional no-start situation occurs when the vehicle continues cranking for five seconds and does not start.

All four of the HEVs tested in this program used the electric motor to start the engine rather than conventional starters. It was observed that while on tank fuel, the Prius would start so imperceptibly that it was impossible to tell when it actually started. The rater was concerned how to record start times during testing. When the same vehicle was started on test fuel, the cranking time became obvious and the rater could tell exactly when the vehicle started. This could be an issue if testing a fuel that gives good starting performance.

One of the idiosyncrasies of the Prius is that it would completely stall and then re-start the engine on its own, with no action on the rater's part. This occurred several times with the Prius and once with one of the Insights. This behavior is not well captured with the current test. An on-site investigation into this issue, Figure 6, did not provide any additional insight into the cause of the problem.

Figure 6, Under Hood Viewing of Toyota Prius HEV

Hybrids can be designed to operate differently, such as the Honda and Toyota vehicles tested. The Honda HEVs provide electric motor assist to a small gasoline engine during take-off and acceleration. When slowing down or braking, energy is recaptured by the same motor serving as a generator. Like the Prius, the Honda system incorporates an idle-stop feature that shuts off the engine at traffic lights. The Toyota Prius operation is based on the driving mode the vehicle is under. The Prius operation can be by the gasoline engine, the electric motor, or a combination of both.

It is unclear how the battery-assist on the Prius operates with severe malfunctions. The Prius had a tendency to display a P3190 malfunction code during several tests. When a P3190 occurred, it resulted in severely restricted operation of the vehicle. The code would be set early in the test procedure, and the rater was able to eventually determine that the engine would be shut down when this code was set. The vehicle would apparently switch to complete battery operation, since there was zero vacuum, there was no indication of idle (the car felt as if it were off), and there was a loss of power. The battery-power indicator on the dash would switch to a large exclamation point. After approximately a half-mile of operation in this mode, the vehicle would completely lose all power and stop. After letting the car sit for a minute or two, the rater could re-crank the engine, the engine would become somewhat operational, and the car would accelerate at a rate of less than five mph. After about a half-mile of this minimal acceleration, the car would begin to gain power and could then be operated normally for another half-mile back to the fueling station. Toyota had issued a repair notification for this situation prior to the program.

Conventional ratings do not always apply to the hybrids. One example is with the Prius. The rater testing the Prius had to develop a unique rating scheme for hesitation with that car. The car would move forward when the accelerator was depressed, but fuel quality had a definite impact on the car's movement. The car might move forward with the vacuum staying at the idle vacuum (nominally 15 inches). Sometimes the car might move forward with a delay in the vacuum dropping to the three inches of light-throttle vacuum. Other times the car might move forward with an immediate vacuum response. Sometimes, the rater could feel the engine engage or "kick in" and sometimes the rater could tell the engine had not "kicked in" during the maneuver.

The preconditioning cycle is another area in which the hybrids are very individualistic. Each model required a different preconditioning cycle to adequately recharge the assist battery. Depending upon the way the Insights were driven, they could use the same preconditioning cycle the conventional vehicles used; however, if they were not driven optimally, this cycle could deplete the assist battery to less than a quarter charge. The Civic required excessively mild accelerations or the battery would be completely depleted, and it could not use the conventional preconditioning cycle. The Prius could be preconditioned using the conventional cycle, but it required moderately mild accelerations. It quickly became obvious that the preconditioning drivers needed to be "trained" how to drive the vehicles to successfully charge them.

The battery charge seems to affect when the battery assist engages. The battery-assist appears to affect engine vacuum. There is some question whether the battery-assist on the hybrids can either simulate or cover-up malfunctions when it engages. The raters made every effort to rate fuel-related malfunctions rather than battery-oriented behavior. Increasing familiarity with the operation of the various hybrids made it easier to distinguish between fuel-related malfunctions and battery-oriented behavior. The raters agreed that becoming familiar with the vehicles is a necessity; in fact, in most cases, it took about a week of testing before the raters began to feel comfortable with the hybrid assigned to them.

All of the hybrid vehicles were de-fueled, flushed, and refueled using a modified version of the standard CRC fueling procedure. The standard fueling procedure (Appendix E) had been developed by the CRC Volatility Group from a study to reduce fuel carryover from one test to the next when flushing vehicle fuel tanks. Figure 7 below shows the two Insights being de-fueled, flushed, and refueled.

Figure 7, Two Honda Insights Being De-fueled, Flushed, and Refueled

Changes to the refueling procedure were to address concerns on battery state of charge and time to refuel. In order to maintain constant battery charge levels, the engines were operated during de-fueling. To reduce overall refueling time, the amount of gasoline used to flush and refuel was changed from four gallons to two gallons. Since these hybrid vehicles had smaller fuel tanks than conventional vehicles, smaller fill size is allowed in the CRC fueling procedure. But even at a 50% reduction in fuel to be drained, the Civic and Prius took longer to de-fuel than most other test vehicles. The drain valve on the Insights needed to be adjusted every five minutes or so, or else surging from the fuel pump would stall the engine. With close attention, the Insights could be drained in an acceptable 20 to 30 minutes. While the program was able to accommodate the varying de-fueling rates, this should be taken into account when planning future hybrid performance testing. If equipment were available to maintain the battery level to fully charged while running the fuel pump, it would simplify the de-fueling by not having to run the engine.

Discussion

The results of these tests must be taken as qualitative, not quantitative, for three reasons. The "fleet" consists of only four vehicles and two are of the same make and model. This sample size is certainly insufficient to draw conclusions about HEVs as a class. Secondly, the vehicles tested best represent the initial sales in the US, as such they are indicative but not definitive of the response to fuel for the complete family of HEVs that will soon be available. Finally, as the subjective results indicate, there is significant reason to believe a more complete cold start and driveaway test could be devised to better evaluate hybrid response to fuel. It is possible that these results do not fully capture the fuel response for even this fleet of vehicles. For these reasons, the LS means have been left graphical, and this discussion will speak primarily in terms of significant or non significant response rather than in numerical terms. The primary observations supported by the analytical analysis are: hybrid vehicle/rater combinations can be discriminated with the current test, HEVs do show a response to fuel variables, and the response is trend-wise similar to that of a fleet of current conventional vehicles.

The vehicle LS means analysis and the GLM analysis both show a significant difference between the Civic and the other three vehicles. While the Civic technology is mildly different from that of the other vehicles, it must be remembered that the rater is totally confounded with the vehicle in these analyses, so no meaningful statements can be made about the vehicle alone. Still, it is clear that at least differences in rater-vehicle combinations can be discriminated by the existing cold start test process.

The fuel response across the four vehicles is significant in the GLM and the LS means analysis, indicating that fuels can be discriminated. As might be expected, based on the literature treating fuel interactions with conventional vehicles, the higher DI fuels have higher TWD (99.99% confidence level) and ethanol degrades performance. In addition, GLM results indicate that the effect of 1% ethanol relative to one point of DI (°F scale) is similar to that observed when the main fleet is analyzed in the same fashion (2). While this similarity could not be predicted with certainty a-priori, the fact that HEVs still use a standard ICE makes this result quite reasonable.

The qualitative fuel results are also in accord with past work (8). While the fleet size cannot justify numerical comparison of means and model effects, it is reassuring that the response observed is in general accord with extensive past experience. However, there is significant reason to believe a better cold-start and warm-up driveability test could be created for use specifically with HEVs.

Based on this conclusion, the authors and the CRC AVFL Committee intend that this piggyback project be followed by a workshop that will focus on the development of a more complete and appropriate HEV cold start driveability test.

The unique operation and performance of HEVs, as discussed above, support the need of such a workshop. There are several HEV issues that should be evaluated during the workshop. They include, but are not limited to, an appraisal of those parts in the existing CRC E-21-94 cycle and warm-up schedule that are inappropriate for HEVs, an appraisal of new or unique aspects of HEV function that interact with fuel and could require new maneuvers to address, a de-fueling and fueling process for HEVs, a warm-up procedure for HEVs including a standard initial SOC that will contribute to assessment of fuel interactions in HEVs, and a way to obtain that SOC with acceptable reproducibility, a cold-start and driveaway test based on the CRC E-21-94 procedures specifically tailored to effectively determine the cold-start and driveaway driveability of HEVs, and possibly a demerit calculation system modification to calculate TWDs over the HEV cycle.

The workshop will be conducted at the same location as the 2003 program--Renegade Raceways in Wapato, Washington, where the desired ambient conditions occur in late January and February and late October and November. The actual season will be chosen based on availability of vehicles.

The timing will be for a two-week period in late January or February or late October or November of 2004. In the first week the vehicles will be prepped and a series of new test patterns will be evaluated. In the second week the best test pattern or best two test patterns will be evaluated on all the vehicles to deturmin the ability to discriminate fuels and the reproducibility of the results. In addition, subjective data will be gathered to detect any faults in the process that may need correction. The last day will be used to de-prep the vehicles, ready them for shipping, and prepare the equipment for storage.

Conclusions

The findings here, although limited, are important to the future testing and evaluation of HEVs. HEVs showed significant variation among vehicle/rater combinations and among fuels using the existing CRC cold-start and warm-up driveability test, indicating that there is a purpose in testing the driveability of this class of vehicles. Using the existing test, hybrids responded to fuel in a manner similar to the conventional vehicles that were tested. In addition, the HEVs tested had unique driving characteristics that made implementation of the existing CRC cold-start and warm-up driveability test problematic. Therefore, a driveability test specifically tailored to HEV characteristics is recommended in order to properly evaluate this class of vehicles. To accomplish this, a new warm-up and refueling process will also be required.

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Definitions, Acronyms, Abbreviations

AVFL: Advanced Vehicle Fuel and Lubricant

Ah: ampere hours

CVT: continuously variable transmission

CRC: Coordinating Research Council

DI: driveability index

ECVT: electronically controlled continuously variable transmission

F: Fahrenheit

FTP: Federal Test Procedure

HEV: hybrid electric vehicle

ICE: internal combustion engine

kg: kilogram

kW: kilowatt

LS: least squares

NREL: National Renewable Energy Laboratory

NiMH: nickel-metal hydride

SOC: state of charge

TWD: total weighted demerits

V: volts

Wh: watt hours

Appendix –A Volatility Program Synopsis

The CRC Volatility Group conducted a program in January and February of 2003 to determine the effect of ethanol content on cold-start and warm-up driveability performance under cool ambient conditions in a large group of late-model vehicles equipped with fuel-injection systems. The goal of the program was to develop concentration-dependent cold-start and warm-up driveability equations for the oxygenate offset of ethanol at cool ambient temperatures.

The Volatility Group tested 27 vehicles which were selected from a total fleet of 80 vehicles, based on their response to DI using the highest DI fuel with the highest concentration of ethanol (Fuel E6). In addition to these 27 vehicles, the CRC Advanced Vehicle/Fuel/Lubricants Committee requested that the Volatility Group test a small number of hybrid vehicles using the same fuels and driveability procedure as the core program. The four hybrid vehicles tested increased the test fleet to 31 vehicles.

The core test program was conducted at Renegade Raceways near Yakima, Washington, from January 27 – February 28, 2003, at ambient temperatures of 30° - 40°F. The majority of the vehicle screening was done at Infineon Raceways in Sonoma County, California, since prior to vehicle selection, it was suggested that vehicles certified to meet California emissions standards, especially SULEV and ULEV vehicles, would be more sensitive.

Appendix –B Driveability Test Procedures and Demerit Rating Details, E-21-94 Process

A. Record all necessary test information at the top of the data sheet.

B. Turn key on for 2 seconds before cranking to pressurize fuel system. Make sure defrost is on and fan is in "low" position. Start engine per Owner's Manual Procedure. Record start time.

C. There may be a total of three starting attempts recorded. If the engine fails to start within 5 seconds on any of these attempts, stop cranking at 5 seconds and record "NS" (no start) in the appropriate starting time box on the data sheet. After the first and second unsuccessful attempts to start, turn the key to the "off" position before attempting to restart per the Owners Manual procedure. If the engine fails to start after 5 seconds during the third attempt, record an "NS" in the Restart2 box, then start the engine any way possible and proceed as quickly as possible to Step D without recording any further start times.

Once the engine starts on any of the first three attempts, idle in park for 5 seconds and record the idle quality. If the engine stalls during this 5-second idle, record a stall in the Idle Park "Stls" box, then restart per the above paragraph, subject to a combined maximum (in any order) of three no-starts and Idle Park stalls. After all the start-time boxes are filled, no further starts should be recorded.

D. Apply brakes (right foot), shift to "Drive" ("Overdrive" if available) for 5-second idle, and record idle quality. If engine stalls, restart immediately. Do not record restart time. Record number of stalls.

A maximum of three Idle Drive stalls may be recorded; however, only one stall contributes to demerits. If the engine stalls a fourth time, restart and proceed to the next maneuver as quickly as possible. It is important to complete the start-up procedure as quickly as possible to prevent undue warm-up before the driving maneuvers and to maintain vehicle spacing on the test track.

E. After idling 5 seconds (Step D), make a brief 0-15 mph light-throttle acceleration. Light-throttle accelerations will be made at a constant throttle opening beginning at a predetermined manifold vacuum. This and all subsequent accelerations throughout the procedure should be "snap" maneuvers: the throttle should be depressed immediately to the position that achieves the pre-set manifold vacuum, rather than easing into the acceleration. Once the throttle is depressed, no adjustment should be made, even if the pre-set vacuum is not achieved. Use moderate braking to stop. Idle for approximately 3 seconds without rating it. Make a brief 0-15 mph light-throttle acceleration. Both accelerations together should be made within 0.1-mile. If both accelerations are completed before the 0.1-mile marker, cruise at 15 mph to the 0.1-mile marker. Use moderate braking to stop; idle for approximately 3 seconds without rating it.

F. Make a 0-20 mph wide-open-throttle (WOT) acceleration beginning at the 0.1-mile marker. Use moderate braking to achieve 10 mph and hold 10 mph until the 0.2-mile marker (approximately 5 seconds). Use moderate braking to stop; idle for approximately 3 seconds without rating it.

G. At the 0.2-mile marker, make a brief 0-15 mph light-throttle acceleration. Use moderate braking to stop. Idle for approximately 3 seconds without rating it. Make a brief 0-15 mph light-throttle acceleration. If accelerations are completed before the 0-3-mile marker, cruise at 10 mph to the 0.3-mile marker.

H. At the 0.3-mile marker, make a light-throttle acceleration from 10-20 mph. Use moderate braking to make a complete stop at the 0.4-mile marker in anticipation of the next maneuver. Idle for approximately 3 seconds at the 0.4-mile marker without rating the idle.

I. Make a 0-20 mph moderate acceleration beginning at the 0.4-mile marker.

J. At the 0.5-mile marker, brake moderately and pull to the right side of the roadway. Idle in "Drive" for 5 seconds and record idle quality. <u>Slowly</u> make a U-turn.

K. Repeat Steps E through J. At the 0.0-mile marker, brake moderately and <u>slowly</u> make a U-turn.

NOTE: Items L-N may be useful only at colder temperatures.

L. Make a crowd acceleration (constant predetermined vacuum) from 0-45 mph. Four-tenths of a mile is provided for this maneuver. Decelerate from 45 to 25 mph before the 0.4-mile marker.

M. At the 0.4-mile marker, make a 25-35 mph detent position acceleration.

N. At the 0.5-mile marker, brake moderately. Idle for 30 seconds in "Drive," recording idle quality after 5 seconds and after 30 seconds, and record any stalls that occur. This ends the driving schedule. Proceed to the staging area.

Definitions of light-throttle, detent, and WOT accelerations are attached. During the above maneuvers, observe and record the severity of any of the following malfunctions (see attached definitions):

1. Hesitation
2. Stumble
3. Surge
4. Stall
5. Backfire

It is possible that during a maneuver, more than one malfunction may occur. Record all deficiencies observed. Do not record the number of occurrences. If no malfunctions occur during a maneuver, draw a horizontal line through all boxes for that maneuver. Also, in recording subjective ratings (T, M, or H), be sure the entry is legible. At times, M and H recordings cannot be distinguished from each other.

Record maneuvering stalls on the data sheet in the appropriate column: accelerating or decelerating. If the vehicle should stall before completing the maneuver, record the stall and restart the car as quickly as possible. Bring the vehicle up to the intended final speed of the maneuver. Any additional stalls observed will not add to the demerit total for the maneuver, and it is important to maintain the driving schedule as closely as possible.

DEFINITIONS AND EXPLANATIONS

Test Run

Operation of a car throughout the prescribed sequence of operating conditions and/or maneuvers for a single test fuel.

Maneuver

A specified single vehicle operation or change of operating conditions (such as idle, acceleration, or cruise) that constitutes one segment of the driveability driving schedule.

Cruise

Operation at a prescribed constant vehicle speed with a fixed throttle position on a level road.

Wide Open Throttle (WOT) Acceleration

"Floorboard" acceleration through the gears from prescribed starting speed. Rate at which throttle is depressed is to be as fast as possible without producing tire squeal or appreciable slippage.

Part-Throttle (PT) Acceleration

An acceleration made at any defined throttle position, or consistent change in throttle position, less than WOT. Several PT accelerations are used. They are:

1. Light Throttle (Lt. Th) - All light-throttle accelerations are begun by opening the throttle to an initial manifold vacuum and maintaining *constant throttle position* throughout the remainder of the acceleration. The vacuum selected is the vacuum setting necessary to reach 25 mph in 9 seconds. The vacuum setting should be determined when the vehicle is cold. The vacuum setting is posted in each vehicle.
2. Moderate Throttle (Md. Th) - Moderate-throttle accelerations are begun by immediately depressing the throttle to the position that gives the pre-specified vacuum and maintaining a *constant throttle position* throughout the acceleration. The moderate-throttle vacuum setting is determined by taking the mean of the vacuum observed during WOT acceleration and the vacuum prescribed for light-throttle acceleration. This setting is to be posted in the vehicle.

3. <u>Crowd</u> - An acceleration made at a constant intake manifold vacuum. To maintain *constant vacuum*, the throttle-opening must be continually increased with increasing engine speed. Crowd accelerations are performed at the same vacuum prescribed for the light-throttle acceleration.
4. <u>Detent</u> - All detent accelerations are begun by opening the throttle to just above the downshift position as indicated by transmission shift characteristic curves. Manifold vacuum corresponding to this point at 25 mph is posted in each vehicle. *Constant throttle position* is maintained to 35 mph in this maneuver.

Malfunctions

1. Stall

   Any occasion during a test when the engine stops with the ignition on. Three types of stall, indicated by location on the data sheet, are:

   a. Stall; idle - Any stall experienced when the vehicle is not in motion, or when a maneuver is not being attempted.

   b. Stall; maneuvering - Any stall which occurs during a prescribed maneuver or attempt to maneuver.

   c. Stall; decelerating - Any stall which occurs while decelerating between maneuvers.

2. Idle Roughness

   An evaluation of the idle quality or degree of smoothness while the engine is idling. Idle quality may be rated using any means available to the lay customer. The rating should be determined by the worst idle quality experienced during the idle period.

3. Backfire

   An explosion in the induction or exhaust system.

4. Hesitation

   A temporary lack of vehicle response to opening of the throttle.

5. Stumble

   A short, sharp reduction in acceleration after the vehicle is in motion.

6. Surge

Cyclic power fluctuations.

Malfunction Severity Ratings

The number of stalls encountered during any maneuver are to be listed in the appropriate data sheet column. Each of the other malfunctions must be rated by severity and the letter designation entered on the data sheet. The following definitions of severity are to be applied in making such ratings.

1. Trace (T) - A level of malfunction severity that is just discernible to a test driver but not to most laymen.

2. Moderate (M) - A level of malfunction severity that is probably noticeable to the average laymen.

3. Heavy (H) - A level of malfunction severity that is pronounced and obvious to both test driver and layman.

4. Extreme (E) - A level of malfunction severity more severe than "Heavy" at which the lay driver would not have continued the maneuver, but taken some other action.

Enter a T, M, H, or E in the appropriate data block to indicate both the occurrence of the malfunction and its severity. More than one type of malfunction may be recorded on each line. If no malfunctions occur, enter a dash (-) to indicated that the maneuver was performed and operation was satisfactory during the maneuver.

DEMERIT CALCULATION SYSTEM

A numerical value for driveability during the CRC test is obtained by assigning demerits to operating malfunctions as shown. Depending upon the type of malfunction, demerits are assigned in various ways. Demerits for poor starting are obtained by subtracting one second from the measured starting time and multiplying by 4. The number of stalls which occur during idle as well as during driving maneuvers are counted separately and assigned demerits as shown. The multiplying x factors of 8 and 32 for idle and maneuvering stalls, respectively, account for the fact that stalls are very undesirable, especially during car maneuvers. A maximum of three total Idle Park stalls and No-Starts are permitted. A maximum of three Idle Drive stalls are permitted.

Other malfunctions, such as hesitation, stumble, surge, idle roughness, and backfire, are rated subjectively by the driver on a scale of trace, moderate, or heavy. For these malfunctions, a certain number of demerits is assigned to each of the subjective ratings. However, since all malfunctions are not of equal importance, the demerits are multiplied by the weighting factors shown to yield weighted demerits.

Finally, weighted demerits, demerits for stalls, and demerits for poor starting are summed to obtain total weighted demerits (TWD), which are used as an indication of driveability during the test. As driveability deteriorates, TWD increases.

A restriction is applied in the totaling of demerits to insure that a stall results in the highest possible number of demerits within a given maneuver. When more than one malfunction occurs during a maneuver, demerits are counted for only the malfunction which had the largest number of weighted demerits. Another restriction is that for each idle period, no more than 3 idle stalls are counted.

When all the factors are multiplied together, the following chart of demerit levels is generated.

Demerit levels for: Hesitation/Stumble/Surge/Backfire/Stall

Maneuver	Stall	Extreme	Heavy	Medium	Trace	Clear
Light Throttle	50	16	8	4	2	0
Medium Throttle	100	32	16	8	4	0
WOT	100	32	16	8	4	0
Detent	50	16	8	4	2	0
Crowd	50	16	8	4	2	0

For Idle Roughness

Extreme	Heavy	Medium	Trace	Clear
8	4	2	1	0

For Idle Stalls

Idle-in- Park	Starting-in-Drive	Other Idle (after moderate throttle or at end of test)
7 each	28	7

For Starting

No Start	Slow Start
25 each	t-1*5

The Start time, t, is in seconds.
Only the results (start, start + stall, no-start) of the first three starting attempts in park count toward demerits.
Only the first stall in drive prior to maneuvering counts toward demerits
Only the first stall in each maneuver, or in each idle subsequent to the start of the maneuver is counted toward demerits.
Only the highest weighted demerit score from each maneuver is counted.

CRC Driveability Data Sheet

					Temperatures		
Run No.	Car	Fuel	Rater	Date	Time	Soak	Run	Odometer

Starting time, Sec.			Idle Park	Idle Drive
Initial	Restart 1	Restart 2	Ruf Stls	Ruf Stls

0.0 0-15 LT TH

H S B
E T S K A D
S M G F C C

0-15 LT TH

H S B
E T S K A D
S M G F C C

0.1 0-20 WOT

H S B
E T S K A D
S M G F C C

0.2 0-15 LT TH

H S B
E T S K A D
S M G F C C

0-15 LT TH

H S B
E T S K A D
S M G F C C

0.3 10-20 LT TH

H S B
E T S K A D
S M G F C C

0.4 0-20 MD TH

H S B
E T S K A D
S M G F C C

0.5 Idle Dr.

Ruf Stls

0.5 0-15 LT TH

H S B
E T S K A D
S M G F C C

0-15 LT TH

H S B
E T S K A D
S M G F C C

0.6 0-20 WOT

H S B
E T S K A D
S M G F C C

0.7 0-15 LT TH

H S B
E T S K A D
S M G F C C

0-15 LT TH

H S B
E T S K A D
S M G F C C

0.8 10-20 LT TH

H S B
E T S K A D
S M G F C C

0.9 0-20 MD TH

H S B
E T S K A D
S M G F C C

0.0 Idle Dr.

Ruf Stls

0.0 0-45 Crowd

H S B
E T S K A D
S M G F C C

0.4 25-35 Detent

H S B
E T S K A D
S M G F C C

0.5 Idle Dr.

5 sec.

Ruf Stls

Idle Dr.

30 sec.

Ruf Stls

Appendix –C Complete Data Set

					TEMPERATURE (°C)		
CAR	FUEL	RATER	DATE	TIME	SOAK	RUN	TWD
84	BASE	1	5-Feb-03	8:25 AM	30	37	81
84	BASE	1	11-Feb-03	8:20 AM	28	37	83.5
84	E1	1	7-Feb-03	9:15 AM	24	36	94.5
84	E1	1	20-Feb-03	7:02 AM	34	41	60
84	E2	1	29-Jan-03	8:35 AM	33	37	36
84	E2	1	18-Feb-03	7:05 AM	35	31	69.5
84	E3	1	6-Feb-03	8:30 AM	26	35	71
84	E3	1	19-Feb-03	6:41 AM	33	36	47.5
84	E4	1	27-Jan-03	9:00 AM	36	42	29.5
84	E4	1	14-Feb-03	6:55 AM	35	38	96
84	E5	1	4-Feb-03	8:24 AM	33	38	99.5
84	E5	1	8-Feb-03	9:15 AM	24	35	102
84	E6	1	28-Jan-03	8:58 AM	36	37	97
84	E6	1	10-Feb-03	8:32 AM	22	36	106
84	H1	1	3-Feb-03	8:36 AM	32	39	59.5
84	H1	1	23-Feb-03	6:40 AM	36	35	69
84	H2	1	1-Feb-03	8:35 AM	35	38	47.5
84	H2	1	17-Feb-03	6:56 AM	37	37	42.5
84	H3	1	2-Feb-03	8:43 AM	32	37	59
84	H3	1	22-Feb-03	6:37 AM	36	38	50.5
85	BASE	2	2-Feb-03	8:43 AM	32	37	100.5
85	BASE	2	18-Feb-03	6:43 AM	35	34	82
85	E1	2	27-Jan-03	8:49 AM	36	42	44
85	E1	2	11-Feb-03	8:22 AM	28	37	41
85	E2	2	5-Feb-03	8:16 AM	30	37	13.5
85	E2	2	20-Feb-03	6:43 AM	34	41	73
85	E3	2	1-Feb-03	8:50 AM	35	39	55
85	E3	2	10-Feb-03	8:34 AM	22	36	47
85	E4	2	7-Feb-03	9:14 AM	24	36	134.5
85	E4	2	23-Feb-03	6:35 AM	36	35	53.5
85	E5	2	6-Feb-03	8:16 AM	26	34	154
85	E5	2	22-Feb-03	6:45 AM	36	38	89.5
85	E6	2	4-Feb-03	8:35 AM	33	38	157
85	E6	2	17-Feb-03	6:57 AM	37	37	164
85	H1	2	29-Jan-03	8:48 AM	33	38	35
85	H1	2	14-Feb-03	6:49 AM	35	38	40
85	H2	2	3-Feb-03	8:39 AM	32	39	56
85	H2	2	19-Feb-03	6:31 AM	34	36	55
85	H3	2	28-Jan-03	8:52 AM	36	36	33
85	H3	2	8-Feb-03	9:17 AM	24	35	80
86	BASE	1	5-Feb-03	8:15 AM	30	36	108
86	BASE	1	11-Feb-03	8:32 AM	28	38	85
86	E1	1	7-Feb-03	7:55 AM	24	30	54.5
86	E1	1	20-Feb-03	6:52 AM	34	41	80.5
86	E2	1	29-Jan-03	8:45 AM	33	38	43

86	E2	1	18-Feb-03	6:55 AM	35	32	43.5
86	E3	1	6-Feb-03	8:15 AM	26	34	88
86	E3	1	19-Feb-03	6:52 AM	34	36	66.5
86	E4	1	27-Jan-03	8:46 AM	36	42	25.5
86	E4	1	14-Feb-03	6:45 AM	35	38	67.5
86	E5	1	4-Feb-03	8:35 AM	33	38	91
86	E5	1	8-Feb-03	9:30 AM	24	36	138
86	E6	1	28-Jan-03	8:46 AM	36	36	115
86	E6	1	10-Feb-03	8:44 AM	22	37	118.5
86	H1	1	3-Feb-03	8:50 AM	32	41	61
86	H1	1	23-Feb-03	6:30 AM	36	35	68.5
86	H2	1	1-Feb-03	8:47 AM	35	39	28
86	H2	1	17-Feb-03	7:07 AM	37	36	52
86	H3	1	2-Feb-03	8:54 AM	32	38	57
86	H3	1	22-Feb-03	6:48 AM	36	39	63.5
87	BASE	3	6-Feb-03	8:18 AM	26	34	21
87	BASE	3	23-Feb-03	6:33 AM	36	35	21
87	E1	3	1-Feb-03	8:51 AM	35	39	20
87	E1	3	17-Feb-03	6:55 AM	37	37	14
87	E2	3	2-Feb-03	8:48 AM	32	37	24
87	E2	3	8-Feb-03	9:19 AM	24	35	26
87	E3	3	28-Jan-03	8:50 AM	36	36	23
87	E3	3	14-Feb-03	6:49 AM	35	38	17
87	E4	3	3-Feb-03	8:51 AM	32	41	38
87	E4	3	22-Feb-03	6:40 AM	36	38	17
87	E5	3	29-Jan-03	8:49 AM	33	38	35
87	E5	3	20-Feb-03	6:51 AM	34	41	18
87	E6	3	5-Feb-03	8:19 AM	30	37	25
87	E6	3	11-Feb-03	8:25 AM	28	37	32
87	H1	3	27-Jan-03	8:49 AM	36	38	41
87	H1	3	19-Feb-03	6:41 AM	34	36	19
87	H2	3	7-Feb-03	9:16 AM	24	36	14
87	H2	3	18-Feb-03	6:53 AM	35	32	11
87	H3	3	4-Feb-03	8:36 AM	33	38	8
87	H3	3	10-Feb-03	8:36 AM	22	36	12

Appendix –D Discussion of the Merits of Log Transformation

The log transform used is not uncommon in improving the treatment of datasets where the dependent variable spans two orders of magnitude; it has been used extensively and effectively in past CRC programs. The transform is taken for TWD+1 to avoid an infinite result in cases where there are no demerits observed. A significant byproduct of the transform is that the effects of the variables in a linear analysis (such as GLM) become multiplicative and the coefficients determined become exponents when the reverse transform is taken. That is to say, the resulting model will be of the form $\mathrm{Ln}(TWD+1)=Av_1+Bv_2+Cv_3+\ldots$ $TWD=V_1^A*V_2^B*V_3^C\ldots-1$ where the A, B, and C are the coefficients determined in the regression, and the v_i are the variable values while the V_i are the exponential of the variables, e.g. $V_1=\exp(v_1)=\exp(DI)$ where DI is the centered value of driveability index.

Appendix –E Program Fueling Procedures

Precautionary notes:

1. ***When draining the vehicle fuel tank, leave the fuel pump on until no drops are coming out of the line. This will ensure that each vehicle fuel tank drain is complete, and the same as the other fuel tank drains.***
2. ***Use a Ul- approved ground strap to ground defueling equipment to the fuel injector rail or fuel line fitting for all fuel draining.***

Flushing Procedure:

1. When a vehicle comes in from testing, hook up the chilled sampling system, and draw the required fuel sample through the Schrader valve or adapter line fitting using the vehicle fuel pump.
2. Remove the sampling system. Immediately prior to testing, install drain line, and then completely drain the fuel tank through the Schrader valve or adapter line fitting using the vehicle fuel pump.
3. Remove the fill cap, add four gallons of the next test fuel to the vehicle fuel tank, and replace the fill cap.
4. Start and idle the vehicle for a total of 2 minutes.
5. Completely drain the fuel tank through the Schrader valve or adapter line fitting using the vehicle fuel pump.
6. Remove the fill cap, add four gallons of the next test fuel to the vehicle fuel tank, and replace the fill cap.
7. Start and idle the vehicle for a total of 2 minutes. From approximately 15 seconds into the idle for a period of 30 seconds, rock the rear end of the vehicle from side to side. This task will require one person on each side of the vehicle.
8. Completely drain the fuel tank through the Schrader valve or adaptive line fitting using the vehicle fuel pump.
9. Remove the fill cap, add four or five gallons as required of the test fuel to the vehicle fuel tank, and replace the fill cap.

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