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AAA PREMIUM FUEL RESEARCH:

Proprietary research into the use of premium octane gasoline when not required by the manufacturer

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Abstract

Automobile engines are designed to meet exhaust emission standards, provide a level of performance commensurate with the vehicle type, and fulfill consumer desires to minimize the day-to-day costs of vehicle operation. On newer models, fuel is the second highest cost of ownership after depreciation [1]. On older vehicles that have already experienced significant depreciation, fuel moves into the top position on the ownership cost list.

To help contain vehicle operating costs, most automakers build the majority of their engines to run on Regular grade gasoline. However, some engines require or recommend the use of Premium gasoline to meet the advertised power output and fuel economy numbers.

Over time, consumers have come to associate Premium gasoline with greater performance, even though the added power actually comes from engine design choices that need high-octane Premium to prevent detonation. Today, many motorists believe that Premium grade gasoline will give engines designed to run on Regular a variety of benefits, including more power, lower tailpipe emissions, and better fuel economy. This paper explores the validity of those beliefs.

In addition, based on AAA data, Premium grade gasoline is typically 23 percent more expensive than Regular gasoline (Appendix 9.1) If there are any benefits to using Premium gasoline in a car that only requires Regular, this paper will address whether they represent a good return on investment.

Primary Research Questions:

1. Does an engine designed to operate on Regular gasoline produce more horsepower when operated on Premium?
    a. Quantitative answer determined by analysis of vehicle data parameters logged during chassis dynamometer runs (city, highway, and aggressive driving cycles) as well as a series of dynamic maximum horsepower tests.
2. Does an engine designed to operate on Regular gasoline get better fuel economy when operated on Premium?
    a. Quantitative answer determined from comparison of driving cycles on a chassis dynamometer equipped with emissions test equipment (city, highway, and aggressive driving cycles) and comparing calculated fuel economy.
3. Does an engine designed to operate on Regular gasoline produce fewer tailpipe emissions when operated on Premium?
    a. Quantitative answer determined from comparison of driving cycles on a chassis dynamometer equipped with emissions test equipment (city, highway, and aggressive driving cycles) and comparing the tailpipe emissions.

Key Findings:

1. Does an engine designed to operate on Regular gasoline produce more horsepower when operated on Premium?

   No consistent differences in maximum horsepower were recorded.

2. Does an engine designed to operate on Regular gasoline get better fuel economy when operated on Premium?

   No significant differences in fuel economy were recorded.

3. Does an engine designed to operate on Regular gasoline produce fewer tailpipe emissions when operated on Premium?

   No consistent differences were recorded.

Contents

1 Introduction

AAA Automotive and Public Relations staff are frequently asked, "Are there any benefits to using Premium gasoline in my car when Regular is recommended by its manufacturer?" This question reflects a commonly held belief that Premium gasoline is somehow better than Regular, and its use can provide a variety of benefits such as more power, lower tailpipe emissions, and higher fuel economy. This paper describes AAA research and quantitative testing that offers fact-based answers on whether Premium gasoline provides any real-world benefits when used in place of Regular.

Figure 1: AAA National Office, Heathrow, FL Image Source: AAA

An automobile is often a person's second most expensive purchase after a home. With vehicle prices climbing and the average service life of automobiles increasing, taking care of the family car is an important consideration. In light of this, giving a car that only requires Regular gasoline an occasional or frequent "treat" by filling it up with Premium might seem like a good idea. But is it?

Automobile engines are designed to meet exhaust emission standards, provide a level of performance commensurate with the vehicle type, and fulfill consumer desires to minimize the day-to-day costs of vehicle operation. On newer models, fuel is the second highest cost of ownership after depreciation [1]. On older vehicles that have already experienced significant depreciation, fuel moves into the top position on the ownership cost list.

To help contain vehicle operating costs, most automakers build the majority of their engines to run on Regular grade gasoline. However, some engines recommend or require the use of Premium to meet the advertised power output and fuel economy numbers. This is particularly true with turbocharged and supercharged engines.

Over time, consumers have come to associate Premium gasoline with greater performance, even though the added power actually comes from engine design choices that need high-octane Premium to prevent detonation. Belief in the superiority of Premium gasoline has also been fostered over the years by oil company marketing campaigns that tout the cleaning abilities of their fuel detergent additive packages.

It should be noted that the use of Premium gasoline comes with significant added cost. Based on AAA data, Premium grade gasoline is typically 23 percent more expensive than Regular gasoline (Appendix 9.1). If any benefits are found when using Premium gasoline in a car that only calls for Regular, this paper will determine if they represent a good return on investment given the higher price of Premium.

1.1 History

The idea that Premium gasoline has unique benefits began in the 1920s when the Ethyl Corporation introduced a gasoline additive, tetraethyl lead (TEL), that suppressed detonation and allowed engine compression ratios to be raised for greater power and efficiency. "Ethyl" gasoline was initially marketed as an upgrade over Regular fuel, but eventually all gasolines adopted TEL additives and "Ethyl" became a generic expression for Premium grade gasolines with superior anti-knock properties. Over time, the term "Premium" gradually replaced "Ethyl," which was a licensed trademark. Ultimately, from 1974 through 1996, leaded gasoline was phased out for on-road use due to health and emissions concerns.

Another contributor to the belief that Premium gasolines are better was the horsepower wars waged from the mid-1950s to around 1970. During this time, automakers raised engine compression ratios and made other changes that required Premium fuel to prevent detonation. Oil companies participated by selling Premium and Super-Premium high-octane gasolines, and during this period they also launched and promoted additive packages that claimed to help keep engines and fuel systems cleaner.

The superiority of Premium gasoline was again touted in the 1980s and 1990s when the widespread adoption of fuel injection resulted in excessive engine carbon deposits, largely due to inadequate fuel detergents. New additive packages were developed, and Premium fuels were frequently advertised as containing more of the detergents necessary to prevent deposit formation.

In 1996, the Environmental Protection Agency (EPA) established Lowest Additive Concentration (LAC) standards that specify a minimum amount of detergent additives in all grades of gasoline. Subsequently, a number of automobile manufacturers created a voluntary TOP TIER™ gasoline standard that requires significantly better additive performance. [2] Both standards call for equal treatment across all grades of gasoline, although there is nothing to prevent an LAC gasoline retailer from boosting detergent content, which is sometimes done exclusively on Premium grade gasoline. Overall, oil companies and retailers continue to focus their promotional efforts on Premium gasoline.

2 Background

Automobile engines have advanced tremendously over the last 125 years. Since the early 1980s, computerized engine controls have enabled a level of driveability, performance, fuel economy and emissions control that that were unthinkable 25 years prior.

The research question, "Am I treating my car with Premium fuel?" is subject to multiple interpretations. If one means "better gas," then that has to focus on the detergent package added to the base fuel stock – since it is the same among all fuel brands. Refer to AAA's primary research, "Not All Gasoline Created Equal" released July 7, 2016. [2]

2.1 Terminology

Terms to be familiar with for better understanding of this report include:

- Internal combustion engine cycle
    - The four-stroke internal combustion engine cycle includes **intake**, **compression**, **power**, and **exhaust** strokes. Spark is introduced to the fuel/air mixture near the top of the compression stroke and the cycle continues, providing power through the drivetrain.
- Detonation
    - The mixture of air and fuel in the engine cylinder is intended to be ignited by the spark plug only. Detonation occurs when the air-fuel charge is compressed by upward motion of the piston and self-ignites before the spark event. This early "firing" event causes a shock wave in the combustion chamber and the metallic "pinging" sound.
- Octane rating
    - A standard rating for the amount of compression an engine fuel can withstand without detonation. While a diesel engine normally operates via compression-ignition, a gasoline engine should not ignite the fuel/air mixture until a spark (of careful timing and duration) is introduced into the compressed air/fuel mixture. Fuels with higher octane ratings are capable of withstanding more compression before suffering detonation.
- Horsepower
    - Torque is the "twisting force" that moves the car from a stop. Exhilarating acceleration from a stand-still – that pushed-back-in-the-seat feeling – is primarily torque, while the ability to accelerate at highway speeds is more in the realm of horsepower. Torque is a measurement while horsepower is a calculation. (Torque * RPM / 5,252 = horsepower)
- Tailpipe emissions and how they are quantified
    - Total hydrocarbons (THC), measured in parts per million Carbon (ppmC), in the exhaust are primarily unburned gasoline.
    - Methane (CH_4), measured in parts-per-million (ppm), is the smallest hydrocarbon molecule and is a subset of the THC measurement. Methane is a greenhouse gas, although it is not a harmful component of air pollution.
    - Non-methane hydrocarbons (NMHC), measured in parts per million, are the volatile organic compounds contributing to air pollution due to high reactivity rates.
    - Carbon monoxide (CO), measured in parts per million, is dangerous in higher concentrations and can lead to fatal air poisoning.
    - Carbon dioxide (CO_2), measured as a percentage of gaseous tailpipe emissions, is a greenhouse gas. The increasing concentration of CO_2 in the atmosphere is identified as a central cause of climate change.
    - Oxides of Nitrogen (NO_x), measured in parts per million, are reactive with ammonia, water vapor, and other compounds to form nitric acid. Small particles can penetrate lung tissue and cause respiratory issues.
- Fuel economy ratings

- The U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA) enforce a codified (Federal Register) system of testing to determine the miles per gallon (MPG) ratings displayed on new vehicle window stickers. [3] Five different driving cycles are completed and a complex formula is applied to generate the city and highway MPG estimates on the new vehicle window sticker. [4]

3 Overall Objective and Methodology

The research is conducted by operating vehicles in a standardized manner with both Regular (87 octane) and Premium (93 octane) gasoline[1]. Comparison of tailpipe emissions, fuel economy, and additional vehicle data allow researchers to quantify the benefit, if any, of using Premium fuel in a vehicle designed to operate on Regular.

EPA driving cycles are used in this research. [4] The city and highway driving cycles are modest in terms of speed and rate of acceleration. They are utilized in this research to determine the effect of increased octane on normal driving. The US06, or aggressive (high speed) driving cycle includes speeds up to 80 MPH and acceleration rates almost three times those of the city and highway driving cycles. This driving profile is included to evaluate the effect of Premium fuel when a vehicle is driven more aggressively, but still realistic to everyday driving conditions.

The maximum horsepower measurement is familiar to racing and performance driving enthusiasts. A wide-open-throttle / peak horsepower test was performed on each vehicle using the Regular and Premium fuels. While not representative of daily driving, this test provides an accurate measure of peak horsepower generated by the test vehicles.

The amount of work necessary for the vehicle to complete the driving cycles (city, highway, and aggressive driving) does not change with fuel grade; it is a constant established by standardized rates and times of acceleration, cruising, and deceleration, in combination with a fixed distance of travel. However, a vehicle's "efficiency" when completing each EPA driving cycle could potentially vary with fuel grade, depending on how well the vehicle's engine is able to take advantage of the octane of a given fuel.

Higher-octane fuels provide greater resistance to engine detonation, or "knock," which allows increased ignition timing advance under certain operating conditions. Greater timing advance provides a longer burn cycle and greater energy extraction from the air/fuel charge in the cylinder, which in turn leads to higher torque and/or horsepower numbers at the flywheel. Under the controlled conditions of the EPA driving cycles, this would theoretically allow smaller throttle openings and reduced fuel delivery during a given driving cycle, with the outcome being better fuel economy.

[1] "Certification fuel" is the technically correct term. This is gasoline that is sourced from a laboratory and is extremely accurate in terms of composition. Refer to Appendix 9.2 for analysis reports of the EPA Tier III Regular and Premium test fuels used in this research.

To test this hypothesis, AAA performed high-rate ignition timing advance measurements[2] on three different vehicles that were certified by their manufacturers using Regular grade gasoline. In the test, each vehicle was driven twice on the three EPA driving cycles using both 87-octane Regular gasoline and 93-octane Premium gasoline to determine if the higher octane Premium delivered any measurable fuel economy benefits and/or decrease in tailpipe emissions. If any benefits were identified, the research examined whether they were cost effective given the higher initial cost of Premium gasoline compared to Regular.

Determining maximum horsepower output was achieved with a dynamometer test. To determine if using Premium fuel provided increased horsepower during road driving conditions, researchers compared the amount of fuel used to complete the fixed work of the driving cycles. Review of ignition timing advance indicated if the vehicle reacted differently to higher octane fuel when performing the fixed amount of work represented by the driving cycles. Refer to section 6.2 for detailed findings.

3.1 Test Vehicles

Three vehicles were selected to allow testing of V-8, V-6, and I-4 engine configurations from a range of vehicle manufacturers. This approach is intended to show how different engine management strategies and spark/fuel systems react to different octane fuels. All vehicles used for testing were obtained from public rental sources.

	Tundra	**Charger**	**Mazda 3**
Model Info		*SXT*	*Grand Touring*
Recommended Fuel	Regular Unleaded	Regular Unleaded	Regular Unleaded
Year	2016	2016	2016
Engine Configuration	V-8	V-6	I-4
Engine Displacement	5.7L	3.6L	2.0L
Valve Timing	Variable	Variable	Variable
Cam Type	DOHC	DOHC	DOHC
Horsepower Rating	381 @ 5600 rpm	292 @ 6350 rpm	155 @ 6000 rpm
Torque Rating	401 @ 3400 rpm	260 @ 4800 rpm	150 @ 4000 rpm
Transmission	6-speed shiftable auto	8-speed shiftable auto	6-speed shiftable auto
Drive Type	4x4 (tested in RWD)	Rear wheel drive	Front wheel drive
Base Curb Weight		3934 lb.	2869 lb.
Gross Vehicle Weight Rating	6700 lb.		
Tire Size	P255/70R18	P215/65R17	P205/60R16
EPA Rating City	13 mpg	19 mpg	30 mpg
EPA Rating Highway	18 mpg	31 mpg	41 mpg
EPA Rating Combined	15 mpg	23 mpg	34 mpg

Figure 2: Test vehicle specifications

3.2 Test Fuel

Certified test fuel was used to remove variability in fuel quality and additives. Gasoline used for testing is EPA Tier III certification fuel in both Regular and Premium octanes with 10 percent ethanol content. The

[2] Refer to Appendix 9.5 for an example of sensor captured (raw) data vs. processed data signal.

certified test fuel is delivered with a laboratory analysis to confirm the fuel quality, additives, and absence of impurities.

See Appendix 9.2 for details on test fuels used.

3.3 Standardized Driving

Uniform driving (repeatability for test) is achieved by using an industry standard chassis dynamometer equipped with emissions test equipment[3], professional operators and drivers, and the EPA's city, highway, and high speed/aggressive driving cycles. [4] These driving scenarios call for operating the vehicle under carefully controlled speed and load conditions. These driving cycles form the core of EPA fuel economy ratings and are repeatable with a high degree of accuracy. Effectively, researchers are able to drive the test vehicle on a set "course" to perform a standard quantity of work. Graphic representation and driving cycle details are provided in Appendix 9.3.

Tailpipe emissions information is collected from each driving cycle with one exception. The high speed / aggressive driving (US06) driving cycle for the V8 engine Tundra is not “bagged” for emissions analysis due to capacity limitations of the constant volume sampling (CVS) emissions test equipment.

3.4 Instrumentation and Data Logging

The dynamometer provides highly accurate logging of speed, resistive load, and calculations of horsepower. The test vehicles are instrumented to collect engine RPM and compute ignition timing directly from the crankshaft position sensor and spark initiation signal. Examples are provided in Appendix 9.4. The data logged directly from the crankshaft position sensor and spark signals was logged at a rate of 1000 Hertz into a DEWESoft data logger. Temperature data from multiple engine locations was similarly logged. Processed data signals were collected from the vehicle's OBD-II port, including comparison values for engine RPM, ignition timing, and engine load absolute percent (PID 43). Processed data signals are obtained at a lower rate (3 times per second) as compared to raw signals captured at 1000 times per second). A comparison of sensor direct (raw) and processed data signals is provided in Appendix 9.5.

3.5 Vehicle Preparation for Testing

All test vehicles were serviced by respective OEM dealerships prior to testing. This includes oil and filter change with parts as recommended by the manufacturer. In addition, all vehicles were checked for needed software updates –particularly those relevant to powertrain control.

3.5.1 Road Miles and Fuel Change-Over

Pump gas is removed from the vehicles and test fuel installed. OBD data for adaptive fuel trim values is reset and all vehicles are driven 50 miles of combination city/highway driving prior to the start of actual

[3] The Automobile Club of Southern California’s Automotive Research Center operates a chassis dynamometer with constant volume sampling (CVS) emissions test equipment.

test procedures. Following testing on 87 octane Regular fuel, excess gasoline is again pumped out, 93 octane Premium test fuel installed, fuel trim reset and another 50 miles of combination city/highway driving to enable adaptation to the different octane fuel prior to repeating tests with the Premium fuel.

4 Inquiry #1: Does an engine designed to operate on Regular gasoline produce more horsepower when operated on Premium?

Objective: Quantify how hard the vehicle is working to complete the prescribed driving cycles. If the maximum horsepower test result is higher with Premium than Regular, then the engine is making more horsepower on the Premium fuel. It's a reasonable observation that most motorists do not operate their vehicle at the very upper limit of its output capability. That is why the test vehicles were also evaluated on the EPA driving cycles.

Researchers addressed this inquiry in two phases: maximum horsepower produced by the vehicle, and an inference of the horsepower produced on Regular vs. Premium fuels during the EPA driving cycles.

4.1 Methodology: Maximum Horsepower

The chassis dynamometer equipment used to conduct the driving cycle tests is used to conduct maximum horsepower trials. Each test vehicle was evaluated for maximum horsepower on both Regular and Premium gasoline. Tests were repeated until a minimum of two comparable runs were recorded for each vehicle/fuel combination. The results obtained in testing are summarized in Appendix 9.6 along with an example dynamometer report. Summary findings are discussed in section 4.2 below.

4.2 Findings: Maximum Horsepower

The vehicles tested did not produce more horsepower when using Premium gasoline. While some differences were recorded when comparing Regular to Premium fuels, they are very small, and are within the expected differences in run-to-run variation for maximum horsepower testing. The data collected does not support any conclusion that Premium fuel allows a vehicle designed for Regular to produce more maximum horsepower.

Maximum horsepower changes comparing Regular to Premium fuels are summarized in the table below. Each entry in the larger chart is an average of two trials. The percentage changes in the smaller chart represent the average change in maximum horsepower from Regular to Premium fuel for each test vehicle. More data on maximum horsepower testing is available in Appendix 9.6.

	Max Horsepower (Hp)	
Trial #1	Regular	Premium
Tundra V-8	290.26	286.03
Charger V-6	236.16	236.60
Mazda3 I-4	126.28	129.78
Trial #2	Regular	Premium
Tundra V-8	289.78	285.26
Charger V-6	235.46	234.12
Mazda3 I-4	126.79	129.25
Average	Regular	Premium
Tundra V-8	290.02	285.65
Charger V-6	235.81	235.36
Mazda3 I-4	126.54	129.52

Premium	Max Horsepower
Tundra V-8	**-1.51%**
Charger V-6	**-0.19%**
Mazda3 I-4	**2.36%**

Figure 3: Maximum horsepower test results (average of two runs)

The engine management systems in modern automobiles make amazingly fast optimization changes and squeeze the most out of every drop of fuel. There are, however competing goals – not all of which contribute to power and fuel economy. Among these is the need to maintain the vehicle's exhaust catalysts in ideal working condition. That means that a large focus of "engine mapping" is keeping the exhaust catalysts working well and then delivering the best performance possible. Even the maximum difference recorded is not substantial enough to be noticeable by the driver. A difference of 3 percent in maximum horsepower output is not quantifiable from the driver's seat during normal, even aggressive driving.

4.3 Methodology: Road Driving Horsepower (Inferred)

Horsepower output during simulated road driving (EPA driving cycles) is inferred. Because the driving cycles (city, highway, and aggressive driving) represent a known value of total work to complete the test cycles, if the vehicle is able to extract more power from the Premium fuel, it would necessarily be able to complete the fixed amount of work using a smaller fuel quantity (i.e., better gas mileage). The engine calibration in a modern vehicle is highly complex, including the combination of spark timing, fuel injection timing and duration, valve timing adjustment, throttle plate opening, and other factors – all adjusted at a rate fast enough to affect each individual combustion cycle. AAA researchers data logged ignition timing advance as a means of determining if the engine behaved differently when using Premium fuel (i.e. more timing advance was applied in higher power requirement sections of the driving cycle).

Two questions are addressed. First, does the vehicle treat the Premium fuel differently? (As evidenced by graphing ignition timing advance.) And second, if Premium fuel is treated differently, does that translate into improved fuel economy – which would indicate that the power necessary to perform a fixed amount of work was extracted from a smaller volume of fuel. By recording ignition advance at a high sample rate, binning the data in increments of 2° timing advance, and comparing the results between runs of the same driving cycle with the Regular fuel and then with Premium fuel differences in vehicle operation (in this case focused on ignition timing) are determined to be due to the different fuel octanes. A histogram is the graphical result of this data analysis method. (Section 4.4)

Quantitative measurement for direct comparison between driving cycle trials on the same octane fuel, and then between Regular and Premium fuels is accomplished by noting the ignition timing advance (when the spark is initiated) for every ignition event on one cylinder of the vehicle's engine. The ignition timing advance parameter is logged at a rate of 1,000 Hz – one thousand times per second.

4.4 Findings: Road Driving Horsepower (Inferred)

Repeat runs of the same driving cycle, by the same test vehicle, using the same octane fuel were very similar in terms of the ignition timing that was logged. Highway fuel economy testing (HWFET) is performed with two back-to-back tests for each driving cycle. This provided for data logged runs to compare ignition timing for each test vehicle, for each octane gasoline. The correlation of these tests was very high (above 0.98 in all cases). Refer to Appendix 9.7 for examples of data correlation and graphing of logged data. The data of like-variable tests was averaged to make an overall comparison of logged ignition timing data when using Regular and Premium fuels.

Differences in vehicle performance / control of ignition timing were apparent only when the test vehicles were operated in an aggressive manner. This was observed only when the test vehicles were driven aggressively: during the high speed/aggressive driving cycle (US06) and in the results of the maximum horsepower tests.

The following graph shows the ignition timing data for the Toyota Tundra during the highway fuel economy test cycle, on both Regular and Premium fuels. Little difference is noted. Results from the other test vehicles were similar, showing very little difference in the ignition timing data during the city and highway driving cycles when operated on Regular and Premium fuels.

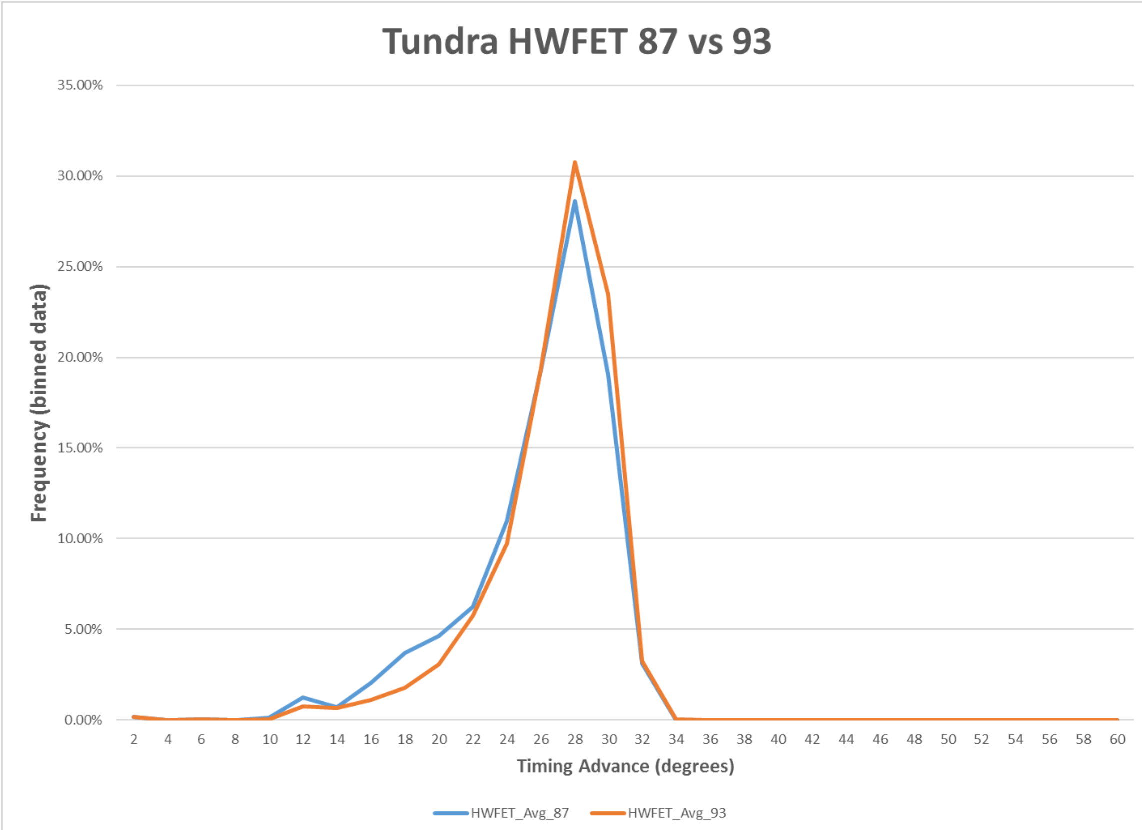

Figure 4:Histogram of ignition timing data - highway fuel economy testing - Regular vs. Premium

The same vehicle during the aggressive (US06) driving cycle shows substantially more difference in timing advance and the graph traces from averaged data are notably different. Results from the two additional test vehicles were similar, showing substantial difference in the logged timing advance data during the US06 aggressive driving cycle when operated on Regular vs. Premium fuel.

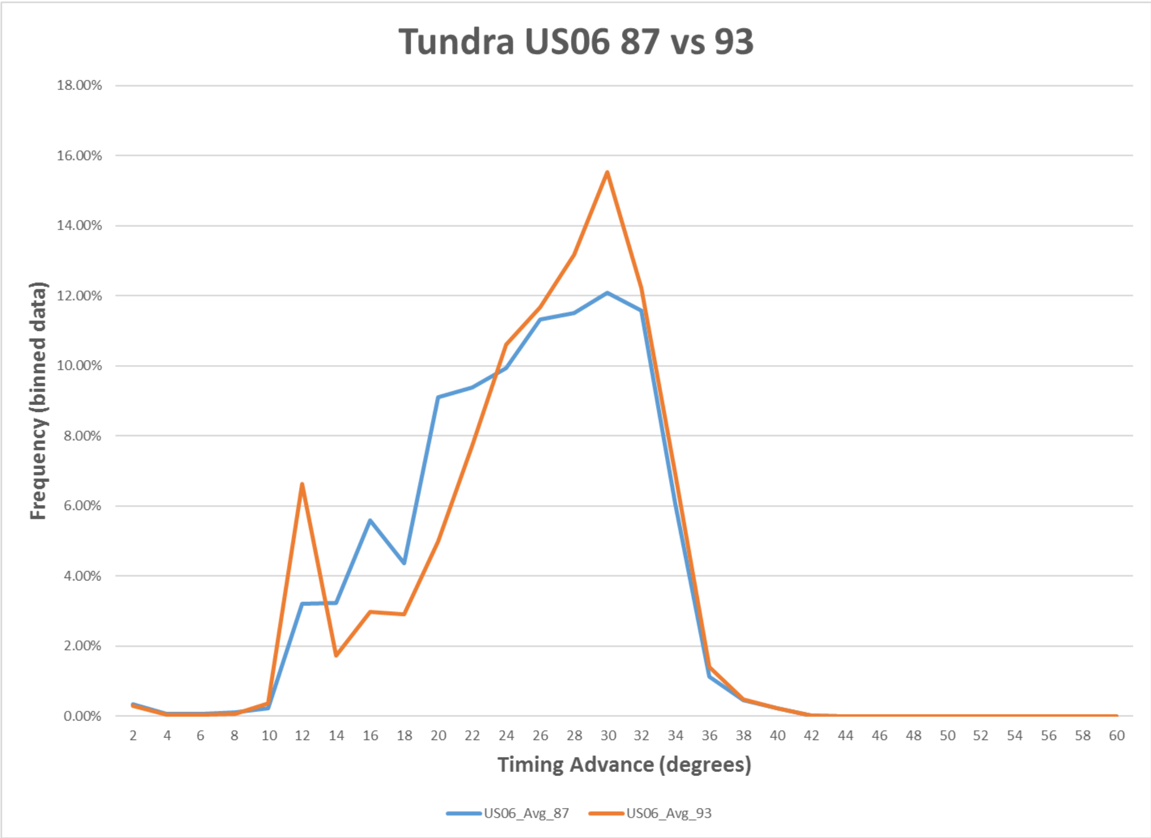

Figure 5: Histogram of ignition timing data - aggressive driving - Regular vs. Premium

However, a difference in how the vehicle responds to higher octane fuel does not necessarily translate into an increase in horsepower. Recapping the methodology section for Road Driving Horsepower (Inferred), the amount of work done to drive the test vehicle in the prescribed manner for each of the EPA driving cycles is fixed[4]. Correlations between the different runs of the same test support the observation that the vehicle is, in fact, driven in a statistically similar manner. To get more power from the higher octane fuel, while performing the same amount of work, would require completing the driving cycle with a lower fuel consumption, that is, a higher gas mileage result. That is not supported by the research findings. Refer to the findings in section 5.2 for details.

[4] For each vehicle. $F = M * A$

5 Inquiry #2: Does an engine designed to operate on Regular gasoline get better fuel economy when operated on Premium?

The tailpipe emissions are directly proportional to the fuel economy (MPG) and, in a controlled laboratory setting with specialized equipment, are the most accurate means of measuring the exact quantity of fuel used by the vehicle. This is how fuel economy numbers are developed for EPA mileage estimates.

5.1 Methodology

If the fuel economy is better on Premium[5] than it is on Regular octane fuel, then the vehicle has, by definition, traveled further on a smaller quantity of gasoline. To quantify this, we measure what comes out of the tailpipe ("bagging" emissions) and calculate backwards to exactly how much fuel was used to power the engine. This task is performed with an industry standard chassis dynamometer and constant volume sampling (CVS) emissions test equipment.

5.2 Findings

Fuel economy is not improved overall when using Premium in a vehicle certified [5] for Regular octane gasoline.

From a fuel cost perspective, the test results do not support spending the extra cost per gallon to put Premium in the tank of a vehicle designed for Regular gasoline. The chart below illustrates the cost[6] to driving 300 miles (representing a tank full of fuel) on Regular 87 octane and Premium 93 octane fuels.

Cost to Drive 300 Miles			
Vehicle	**EPA Combined**	**Regular**	**Premium**
Tundra V-8	15	$44.68	$54.82
Charger V-6	23	$29.14	$35.75
Mazda3 I-4	34	$19.71	$24.19

Figure 6: Fuel cost to drive 300 miles

The differences in fuel economy, as noted in the chart below, are very small – the differences in fuel economy using Premium instead of Regular are actually less than the variation between trials using the same fuel[7]. Each bar in the chart below represents the average of two trials. Note that the fuel economy numbers are only applicable for the test performed. The EPA city and highway fuel economy numbers

[5] AAA used a certified test fuel (with appended chemical analysis) and 10% ethanol to match what the majority of Americans purchase at the pump. Limiting the variables to just what is different in the fuel.
[6] Based on nationwide average reported Regular and Premium fuel costs. See Appendix 9.1 for date and details.
[7] Same fuel, same driving cycle variation range absolute: 0.05% to 2.28%; Average delta MPG achieved on Premium compared to Regular: 0.21%

found on a vehicle window sticker are the result of additional tests and a complex mathematical weighting [6].

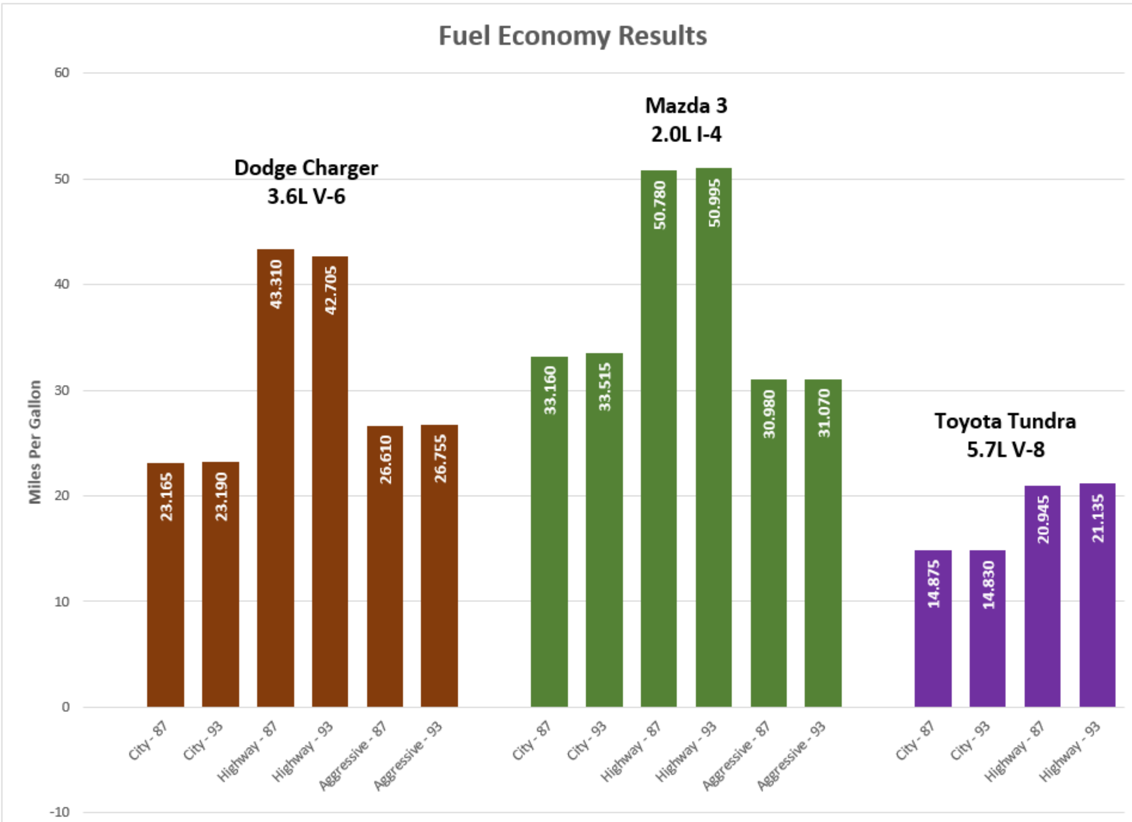

Figure 7: Average fuel economy on Regular and Premium by driving cycle (average of two)

6 Inquiry #3: Does an engine designed to operate on Regular gasoline produce fewer tailpipe emissions when operated on Premium?

6.1 Methodology

Test vehicles are operated first on Regular (87 octane) and driven through the EPA test cycles for city, highway, and aggressive driving. Multiple trials are performed for each test cycle to ensure consistent, repeatable results. A statistical correlation of the trials is provided in Appendix 9.7. Tailpipe emissions are collected and analyzed during the EPA driving cycles[8] to determine the exact quantity of fuel used by the engine during the test.

[8] Exception: tailpipe emissions are not bagged for the Toyota Tundra V8 during the high speed/aggressive driving cycle (US06). This is due to a capacity limitation on constant volume sampling (CVS) emissions test equipment. All other data is collected as described in section 3.4.

Figure 8: Test vehicle on chassis dynamometer at Automotive Research Center

An example of the emissions dynamometer report showing fuel economy during the test is provided in Appendix 9.8. The following chart summarizes tailpipe emissions during all test cycles for all three test vehicles. Tailpipe emissions results for all vehicles over all test cycles were very close and did not show a trend toward increasing or decreasing a particular exhaust component.

6.2 Findings

The amount of variation found in testing is normal for emissions testing, as there will always be some variability. Referencing the chart below, no consistent differences were recorded for the different emissions components across the three test vehicles and the three driving cycles. Carefully measured tailpipe emissions are not uniformly less on Premium than on Regular fuel. Data shown is an average of two test runs for each driving cycle. The shading provided indicates where test values for Premium fuel differ from those with Regular fuel. There are multiple ways to review the data. Shading where values fluctuate is intended to facilitate review and not to indicate overall improvement of tailpipe emissions – which was not noted.

Vehicle	Fuel	Odometer	Test Cycle	Start Cond.	THC	CH4	NMHC	NOX	CO	CO2
Charger	Regular	Averages	City (75FTP)	Cold	0.0277	0.0070	0.02085	0.0100	0.4376	371.575
Charger	Premium	Averages	City (75FTP)	Cold	0.0285	0.0067	0.02205	0.0140	0.4151	372.190
Charger	Regular	Averages	Highway (HWFET)	Hot	0.0004	0.0005	0.00000	0.0010	0.0661	199.050
Charger	Premium	Averages	Highway (HWFET)	Hot	0.0007	0.0007	0.00000	0.0000	0.0729	202.395
Charger	Regular	Averages	Aggressive (US06)	Hot	0.0140	0.0033	0.01055	0.0176	0.3041	323.580
Charger	Premium	Averages	Aggressive (US06)	Hot	0.0111	0.0034	0.00760	0.0125	0.1768	322.995
Mazda3	Regular	Averages	City (75FTP)	Cold	0.0092	0.0027	0.00685	0.0100	0.1684	259.810
Mazda3	Premium	Averages	City (75FTP)	Cold	0.0093	0.0025	0.00705	0.0089	0.1429	257.800
Mazda3	Regular	Averages	Highway (HWFET)	Hot	0.0001	0.0003	0.00000	0.0032	0.0224	169.805
Mazda3	Premium	Averages	Highway (HWFET)	Hot	0.0002	0.0001	0.00010	0.0032	0.0335	169.530
Mazda3	Regular	Averages	Aggressive (US06)	Hot	0.0099	0.0024	0.00745	0.0031	0.7669	277.220
Mazda3	Premium	Averages	Aggressive (US06)	Hot	0.0080	0.0020	0.00595	0.0033	0.7894	277.145
Tundra	Regular	Averages	City (75FTP)	Cold	0.0257	0.0043	0.02175	0.0146	0.2335	579.360
Tundra	Premium	Averages	City (75FTP)	Cold	0.0272	0.0050	0.02265	0.0145	0.2320	582.730
Tundra	Regular	Averages	Highway (HWFET)	Hot	0.0024	0.0014	0.00100	0.0048	0.0532	411.745
Tundra	Premium	Averages	Highway (HWFET)	Hot	0.0000	0.0004	0.00000	0.0042	0.0651	409.135
Tundra	Regular	Averages	Aggressive (US06)	Hot	Exhaust emissions on US06 test not bagged due to capacity limitations of emissions testing equipment.					
Tundra	Regular	Averages	Aggressive (US06)	Hot						

Figure 9: Tailpipe emissions results (average of two tests)

7 Summary Recommendations

The automobile is often a person's second most expensive life purchase. After depreciation, fuel costs are likely to be among the highest spending category for annual cost to drive. With the trend toward vehicles costing more and lasting longer, it makes more sense than ever to take care of your car. Based upon AAA's testing, motorists are not treating their vehicle in any meaningful way by using Premium when the vehicle is designed to run on Regular fuel.

AAA calculated that U.S. drivers waste **$2.1 billion** annually by putting Premium gasoline into vehicles designed to run on Regular. See Appendix 9.9 for details on survey data used in this calculation.

To treat your car, AAA recommends focusing on keeping maintenance up to date and using TOP TIER™ rated gasolines in the octane rating specified in your vehicle owner's manual (or on the gas cap). For more information on fuel quality (not octane), refer to AAA's research report, "Not All Gasoline Created Equal" available from the AAA Newsroom. [2]

8 References

[1] AAA, "Your Driving Costs," 2016. [Online]. Available: http://newsroom.aaa.com/auto/your-driving-costs/. [Accessed 12 July 2016].

[2] AAA, "Not All Gasoline Created Equal," 2016. [Online]. Available: http://newsroom.aaa.com/2016/07/aaa-not-gasoline-created-equal/. [Accessed 12 July 2016].

[3] Environmental Protection Agency, "Vehicle labeling of fuel economy, greenhouse gas, and other pollutant emissions information.," Federal Register, 2008.

[4] U.S. Environmental Protection Agency, "Detailed Test Information," [Online]. Available: www.fueleconomy.gov. [Accessed 12 July 2016].

[5] U.S. EPA, "Model Year 2016 Fuel Economy Guide," [Online]. Available: https://www.fueleconomy.gov/feg/pdfs/guides/FEG2016.pdf .

[6] U.S. EPA, "Final Technical Support Document: Fuel Economy Labeling of Motor Vehicle Revisions to Improve Calculation of Fuel Economy Estimates," December 2006. [Online]. Available: https://www3.epa.gov/carlabel/documents/420r06017.pdf. [Accessed 01 08 2016].

[7] AAA, "Gas Prices," [Online]. Available: http://gasprices.aaa.com. [Accessed 9 July 2016].

9 Appendices

9.1 Average Gasoline Prices

National prices averaged from 8/27/2015 to 8/26/2016 yield a price increase of **49.33 cents per gallon or 23%** for Premium gasoline compared to Regular.

The following chart summarizes U.S. National prices for gasoline and indicates the percent increase in price per gallon paid for Premium grade fuel over Regular.

	National			
Sample date: 8/26/2016	**Regular**	**Premium**	**delta**	**percent**
Daily Average (365 days)	2.1193	2.6126	0.4933	23.28%
current average	2.2054	2.6955	0.4901	22.22%
yesterday's average	2.1975	2.6894	0.4919	22.38%
week ago average	2.1410	2.6459	0.5049	23.58%
month ago average	2.1539	2.6728	0.5189	24.09%
year ago average	2.5563	3.0400	0.4837	18.92%

Figure 10: Summary of gasoline price historical data

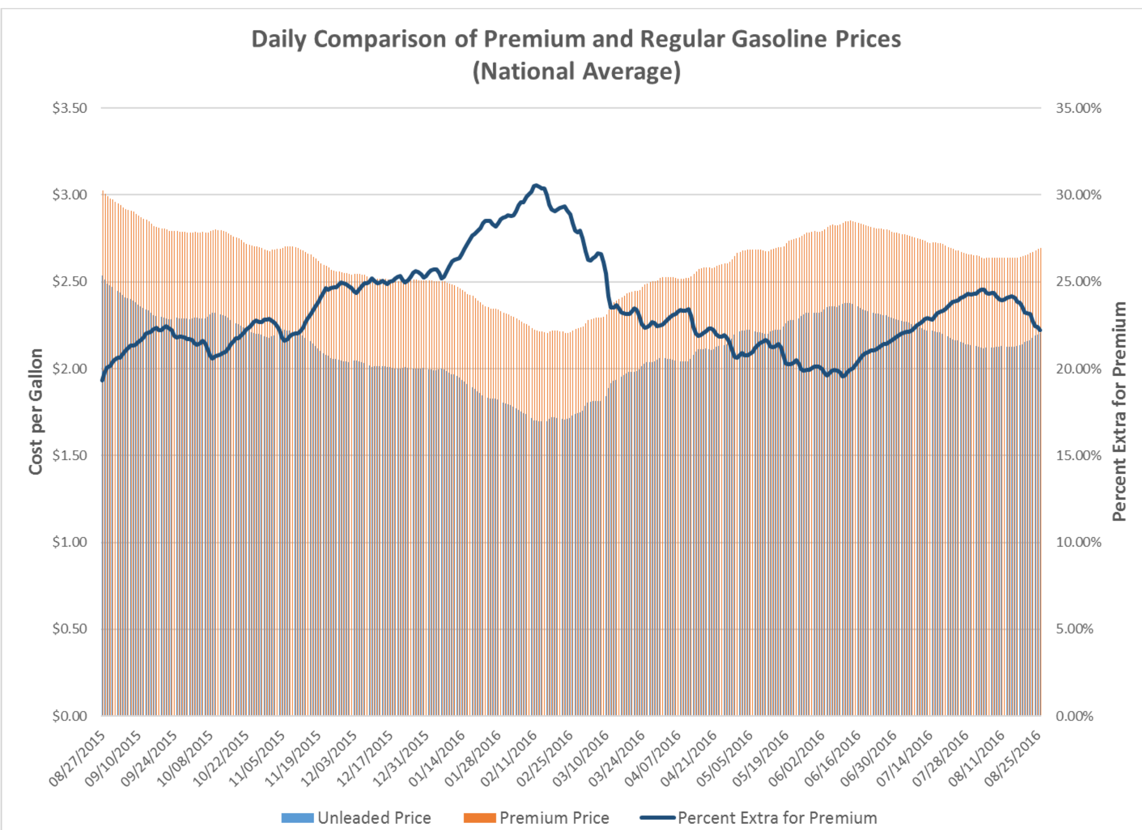

Figure 11: Extra cost for Premium fuel over one year

Data source is GasPrices.AAA.com

9.2 Certification Fuel

9.2.1 87 Octane (Regular)

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fueling the world, one solution at a time

Product Information

Telephone: (800) 969-2542 **FAX: (281) 457-1469**

Johann Haltermann Ltd.

PRODUCT: EPA Tier 3 EEE Emission Certification Fuel, General Testing - Regular

Batch No.: CI0921LT10

Tank No.: 126

Specification No.: HF2021

TEST	METHOD	UNITS	SPECIFICATIONS			RESULTS
			MIN	TARGET	MAX	
Distillation - IBP	ASTM D86	°F				94.9
5%		°F				118.3
10%		°F	120		140	127.8
20%		°F				139.2
30%		°F				147.8
40%		°F				154.8
50%		°F	190		210	198.2
60%		°F				233.3
70%		°F				257.4
80%		°F				281.5
90%		°F	315		335	318.0
95%		°F				338.3
Distillation - EP		°F	380		420	385.8
Recovery		ml		Report		97.2
Residue		ml			2.0	1.0
Loss		ml				1.9
Gravity @ 60° F	ASTM D4052	°API		Report		57.92
Density @ 15.56° C	ASTM D4052	-		Report		0.7461
Reid Vapor Pressure EPA Equation	ASTM D5191	psi	8.7		9.2	9.2
Carbon	ASTM D5291	wt fraction		Report		0.8254
Hydrogen	ASTM D5291	wt fraction		Report		0.1367
Hydrogen/Carbon ratio	ASTM D5291	mole/mole		Report		1.974
Oxygen	ASTM D4815	wt %		Report		3.80
Ethanol content	ASTM D5599-00	vol%	9.6		10.0	9.9
Total oxygentates other than ethanol	ASTM D4815	vol%			0.1	None Detected
Sulfur	ASTM D5453	mg/kg	8.0		11.0	9.6
Phosphorus	ASTM D3231	g/l			0.0013	None Detected
Lead	ASTM D3237	g/l			0.0026	None Detected
Composition, aromatics	ASTM D5769	vol %	21.0		25.0	23.3
C6 aromatics (benzene)	ASTM D5769	vol %	0.5		0.7	0.5
C7 aromatics (toluene)	ASTM D5769	vol %	5.2		6.4	5.9
C8 aromatics	ASTM D5769	vol %	5.2		6.4	6.0
C9 aromatics	ASTM D5769	vol %	5.2		6.4	5.8
C10+ aromatics	ASTM D5769	vol %	4.4		5.6	5.1
Composition, olefins	ASTM D6550	wt%	4.0		10.0	5.0
Oxidation Stability	ASTM D525	minutes	1000			1000+
Copper Corrosion	ASTM D130				1	1a
Existent gum, washed	ASTM D381	mg/100mls			3.0	<0.5
Existent gum, unwashed	ASTM D381	mg/100mls		Report		1.0
Research Octane Number	ASTM D2699			Report		91.2
Motor Octane Number	ASTM D2700			Report		83.2
R+M/2	D2699/2700		87.0		88.4	87.2
Sensitivity	D2699/2700		7.5			8.0
Net Heat of Combustion	ASTM D240	BTU/lb		Report		18007

Figure 12: Certification fuel analysis (Regular)

9.2.2 93 Octane (Premium)

haltermannsolutions

fueling the world, one solution at a time

Product Information

Telephone: (800) 969-2542 **FAX: (281) 457-1469**

Johann Haltermann Ltd.

PRODUCT:	**EPA Tier 3 EEE Emission Certification Fuel, General Testing - Premium**	**Batch No.:**	DE2221LT10
		Tank No.:	121
Specification No.:	**HF2042**		

TEST	METHOD	UNITS	SPECIFICATIONS			RESULTS
			MIN	TARGET	MAX	
Distillation - IBP	ASTM D86	°F				101.7
5%		°F				125.1
10%		°F	120		140	133.4
20%		°F				143.8
30%		°F				151.6
40%		°F				155.3
50%		°F	190		210	204.7
60%		°F				225.7
70%		°F				248.0
80%		°F				278.5
90%		°F	315		335	324.2
95%		°F				340.4
Distillation - EP		°F	380		420	380.7
Recovery		vol %		Report		97.4
Residue		vol %			2.0	0.9
Loss		vol %				1.7
Gravity @ 60° F	ASTM D4052	°API		Report		58.1
Density @ 15.56° C	ASTM D4052	-				0.7455
Reid Vapor Pressure EPA Equation	ASTM D5191	psi	8.7		9.2	8.91
Carbon	ASTM D5291	wt fraction		Report		82.49
Hydrogen	ASTM D5291	wt fraction		Report		13.90
Hydrogen/Carbon ratio	ASTM D5291	mole/mole		Report		2.008
Oxygen	ASTM D4815	wt %		Report		3.61
Ethanol content	ASTM D5599-00	vol%	9.6		10.0	9.8
Total oxygentates other than ethanol	ASTM D4815	vol%			0.1	None Detected
Sulfur	ASTM D5453	mg/kg	8.0		11.0	9.8
Phosphorus	ASTM D3231	g/l			0.0013	None Detected
Lead	ASTM D3237	g/l			0.0026	None Detected
Composition, aromatics	ASTM D5769	vol %	21.0		25.0	23.0
C6 aromatics (benzene)	ASTM D5769	vol %	0.5		0.7	0.6
C7 aromatics (toluene)	ASTM D5769		5.2		6.4	5.8
C8 aromatics	ASTM D5769		5.2		6.4	5.8
C9 aromatics	ASTM D5769		5.2		6.4	5.9
C10+ aromatics	ASTM D5769		4.4		5.6	4.9
Composition, olefins	ASTM D6550	wt%	4.0		10.0	4.5
Oxidation Stability	ASTM D525	minutes	1000			1000+
Copper Corrosion, 3 hr @ 50 °C	ASTM D130				1	1a
Existent gum, washed	ASTM D381	mg/100mls			3.0	<0.5
Existent gum, unwashed	ASTM D381	mg/100mls		Report		1.5
Research Octane Number	ASTM D2699			Report		97.4
Motor Octane Number	ASTM D2700			Report		87.5
R+M/2	D2699/2700		91.0			92.4
Sensitivity	D2699/2700		7.5			9.9
Net Heat of Combustion	ASTM D240	BTU/lb		Report		17897

Figure 13: Certification fuel analysis (Premium)

9.3 EPA Driving Cycles

The following information is available at www.fueleconomy.gov. Navigate to “About EPA Ratings” and then “Detailed Test Information”

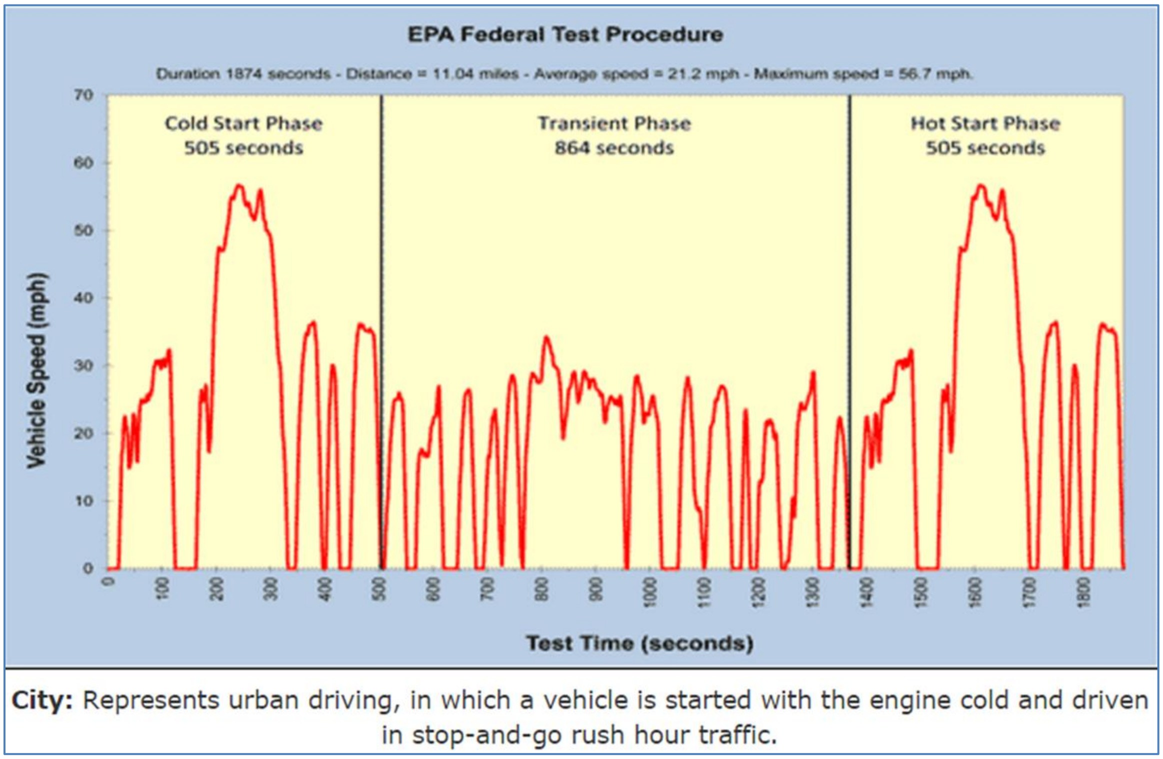
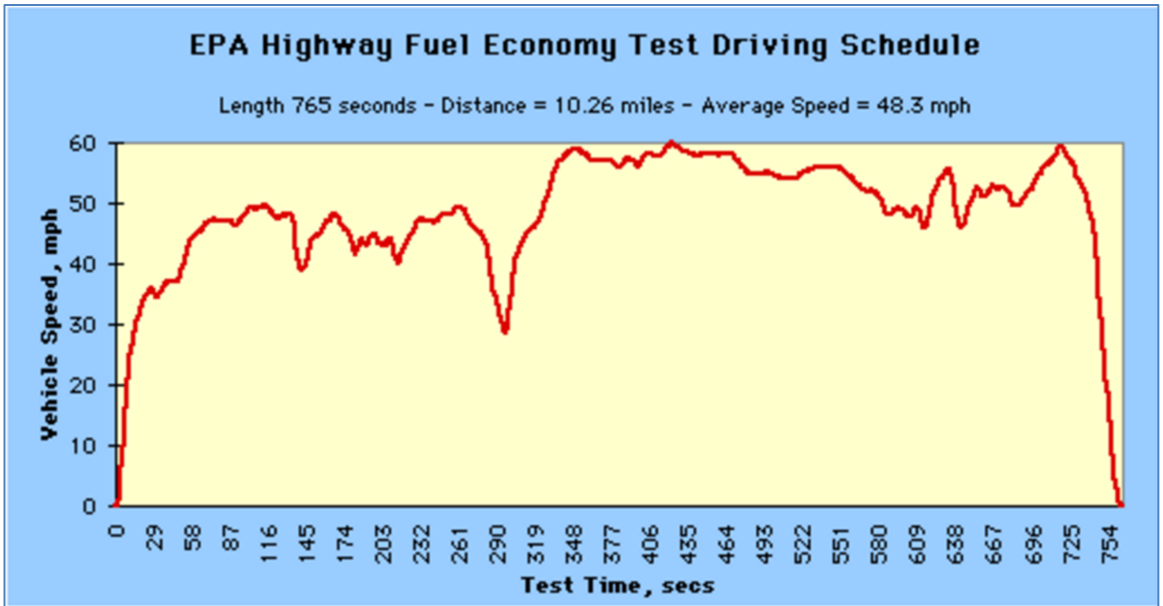
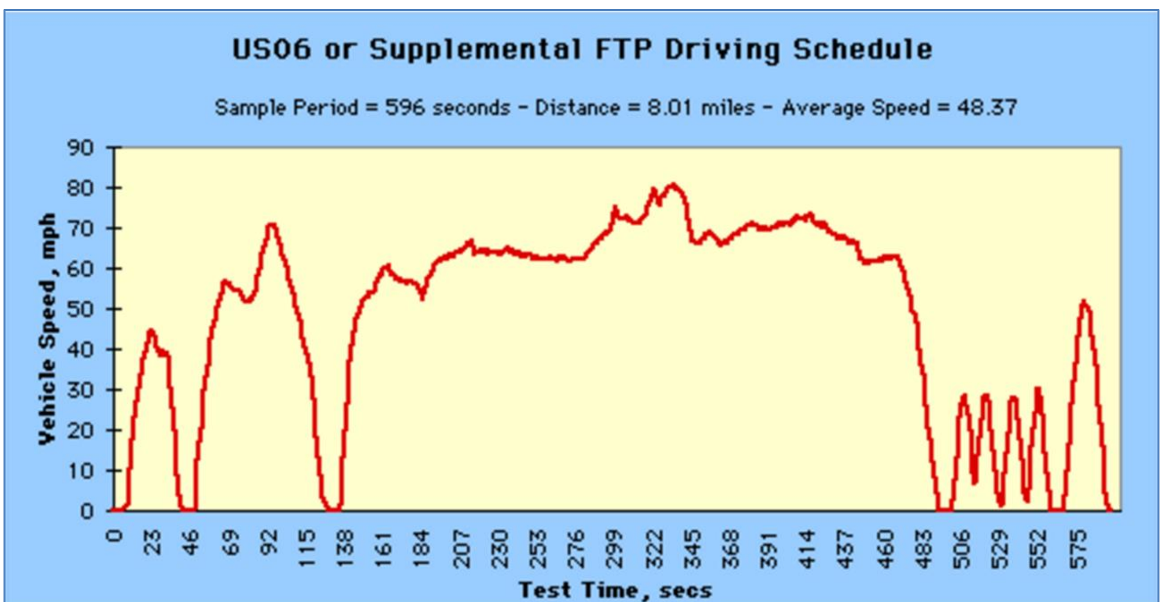


Figure 14: City driving cycle (FTP)



Highway: Represents a mixture of rural and Interstate highway driving with a warmed-up engine, typical of longer trips in free-flowing traffic.

Figure 15: Highway driving cycle (HWFET)



High Speed: Represents city and highway driving at higher speeds with more aggressive acceleration and braking.

Figure 16: Aggressive driving cycle (US06)

Test Cycle Attributes	Test Cycle				
	City	Highway	High Speed	A/C	Cold Temp
Trip Type	Low speeds in stop-and-go urban traffic	Free-flow traffic at highway speeds	Higher speeds; harder acceleration & braking	A/C use under hot ambient conditions	City test w/ colder outside temp.
Top Speed	56 mph	60 mph	**80 mph**	54.8 mph	56 mph
Average Speed	21.2 mph	48.3 mph	48.4 mph	21.2 mph	21.2 mph
Max. Acceleration	3.3 mph/sec	3.2 mph/sec	**8.46 mph/sec**	5.1 mph/sec	3.3 mph/sec
Simulated Distance	11 mi.	10.3 mi.	8 mi.	3.6 mi.	11 mi.
Time	31.2 min.	12.75 min.	9.9 min.	9.9 min.	31.2 min.
Stops	23	None	4	5	23
Idling time	18% of time	None	7% of time	19% of time	18% of time
Engine Startup*	**Cold**	Warm	Warm	Warm	**Cold**
Lab temperature	68ºF–86ºF			**95ºF**	**20ºF**
Vehicle air conditioning	Off	Off	Off	**On**	Off

* A vehicle's engine doesn't reach maximum fuel efficiency until it is warm.

Figure 17: Detailed test information

9.4 Crankshaft Position and Spark Initiation

The following are examples of crankshaft position sensor and coil trigger signals recorded to determine ignition timing advance.

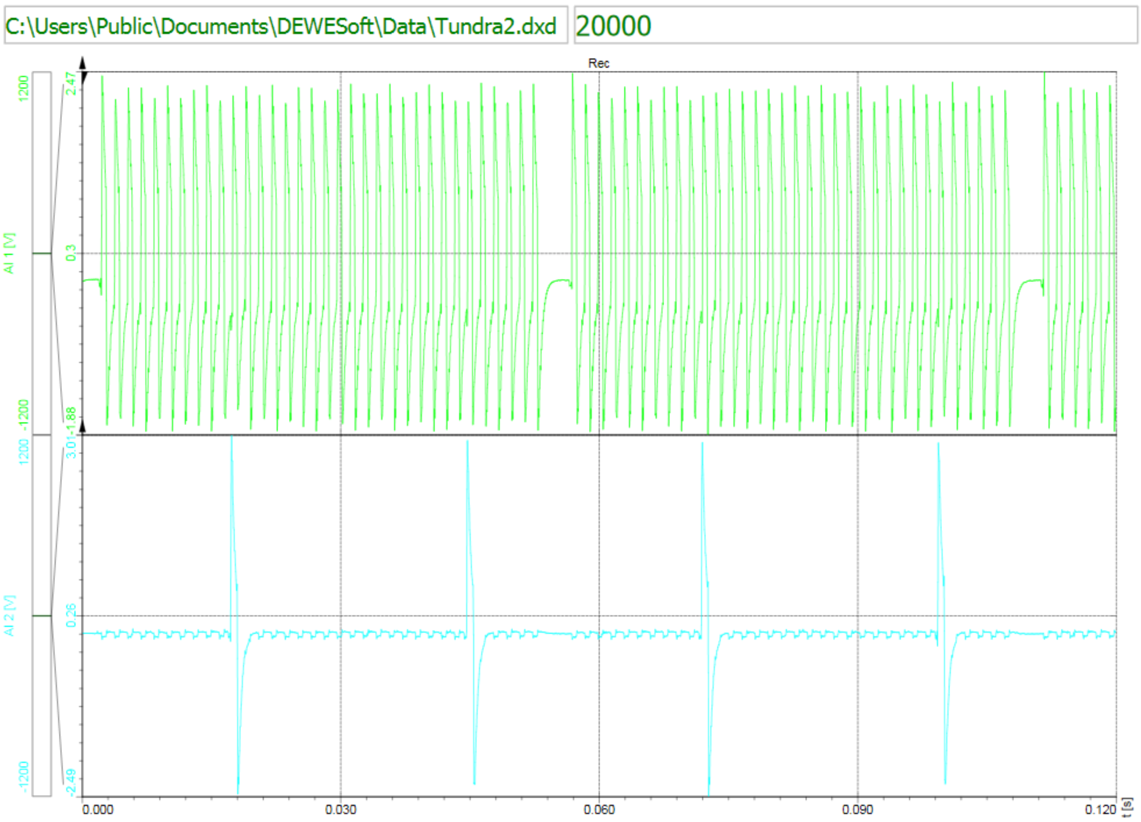


Figure 18: Toyota Tundra V-8 crankshaft position and coil trigger

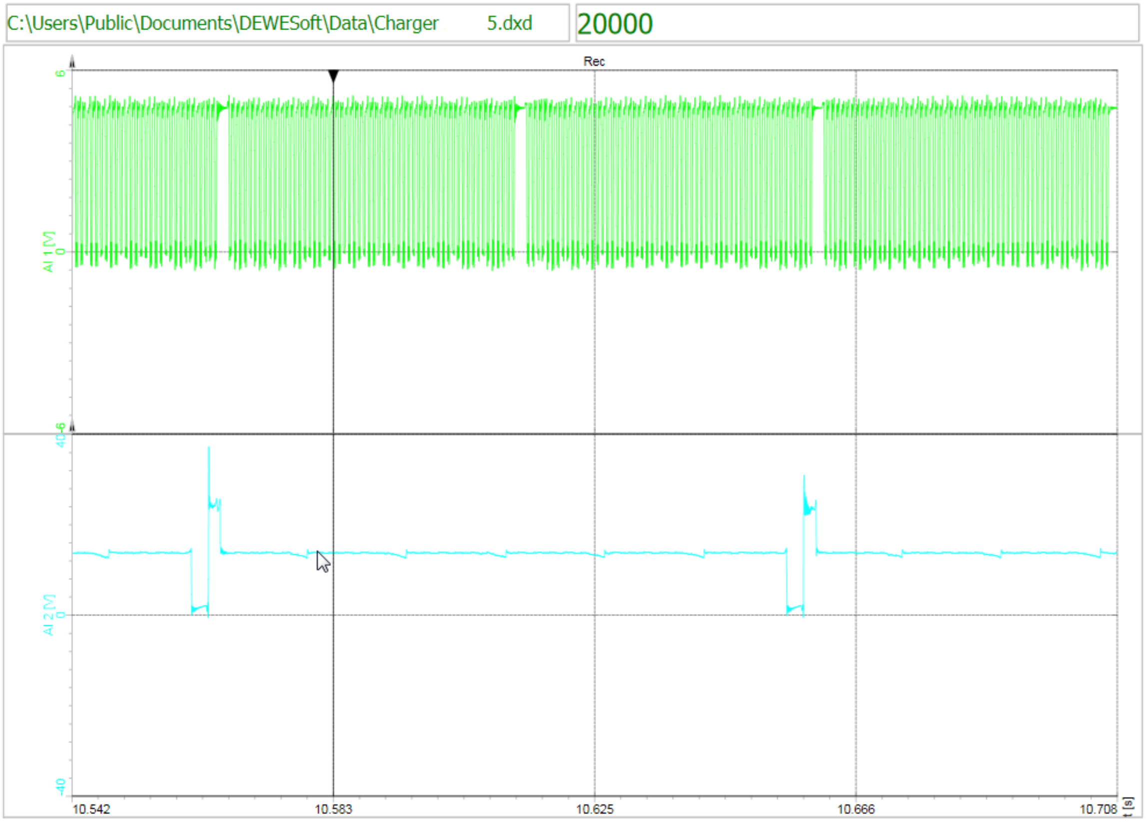


Figure 19: Dodge Charger V-6 crankshaft position and coil trigger

9.5 Sensor Captured (Raw) versus Processed Data Signals

The image below represents 20 seconds out of the total 596 seconds of the US06 driving cycle.

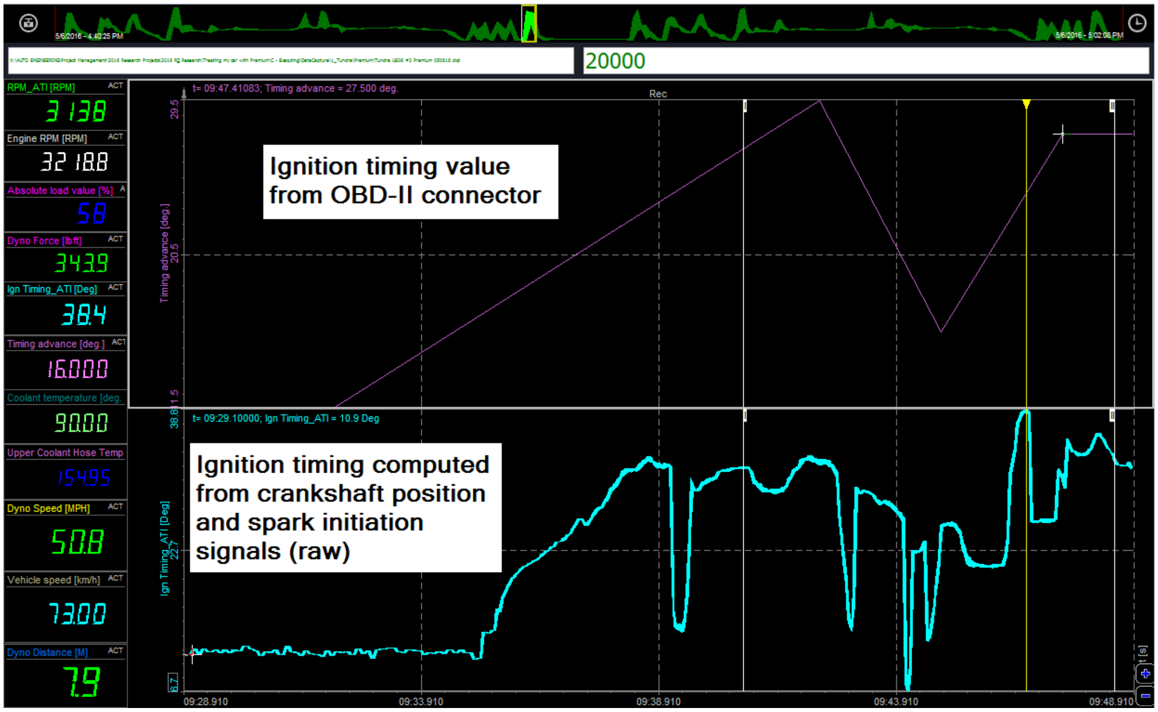


Figure 20: Data logger trace showing difference in processed and direct data

9.6 Maximum Horsepower

The chart below summarizes data from maximum horsepower testing on all three test vehicles, with both Regular and Premium gasoline. Each data point graphed is a single test run. In section 4.2, the data presented in the results chart is the average of each pair of test runs.

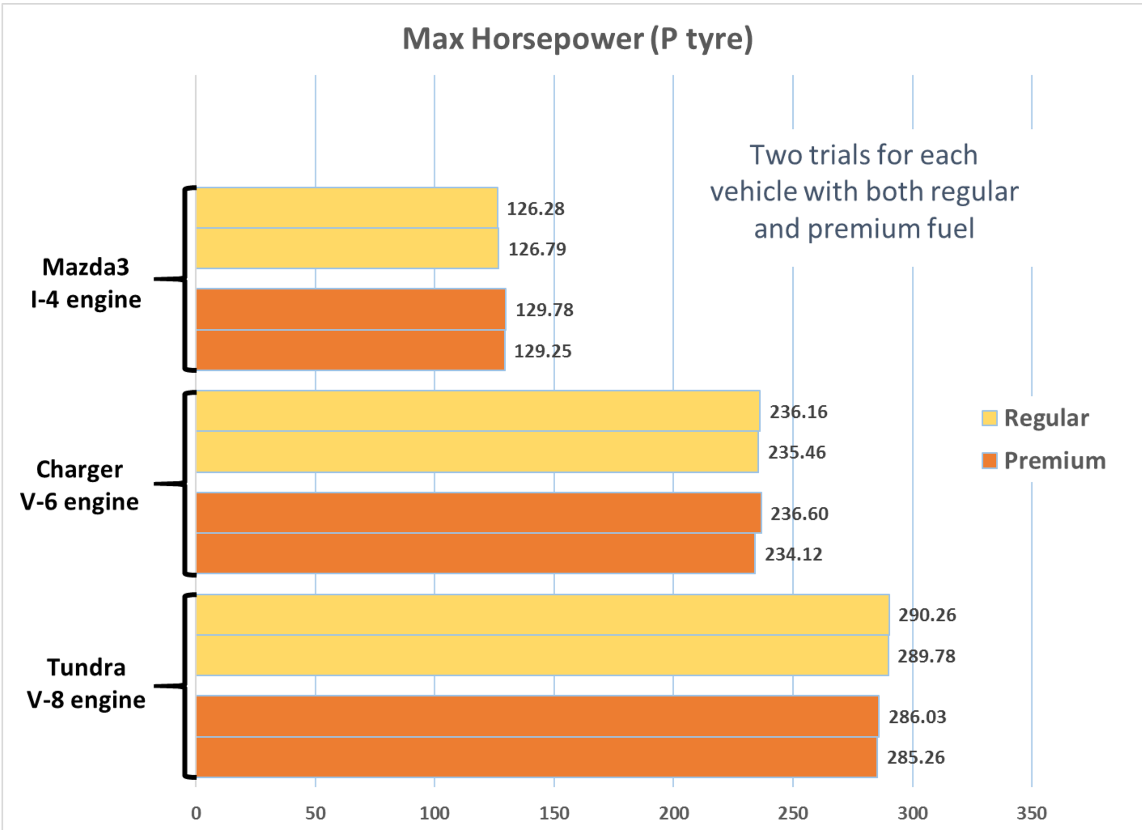


Figure 21: Maximum horsepower test results

The following graphs are dynamometer reports from maximum horsepower testing.

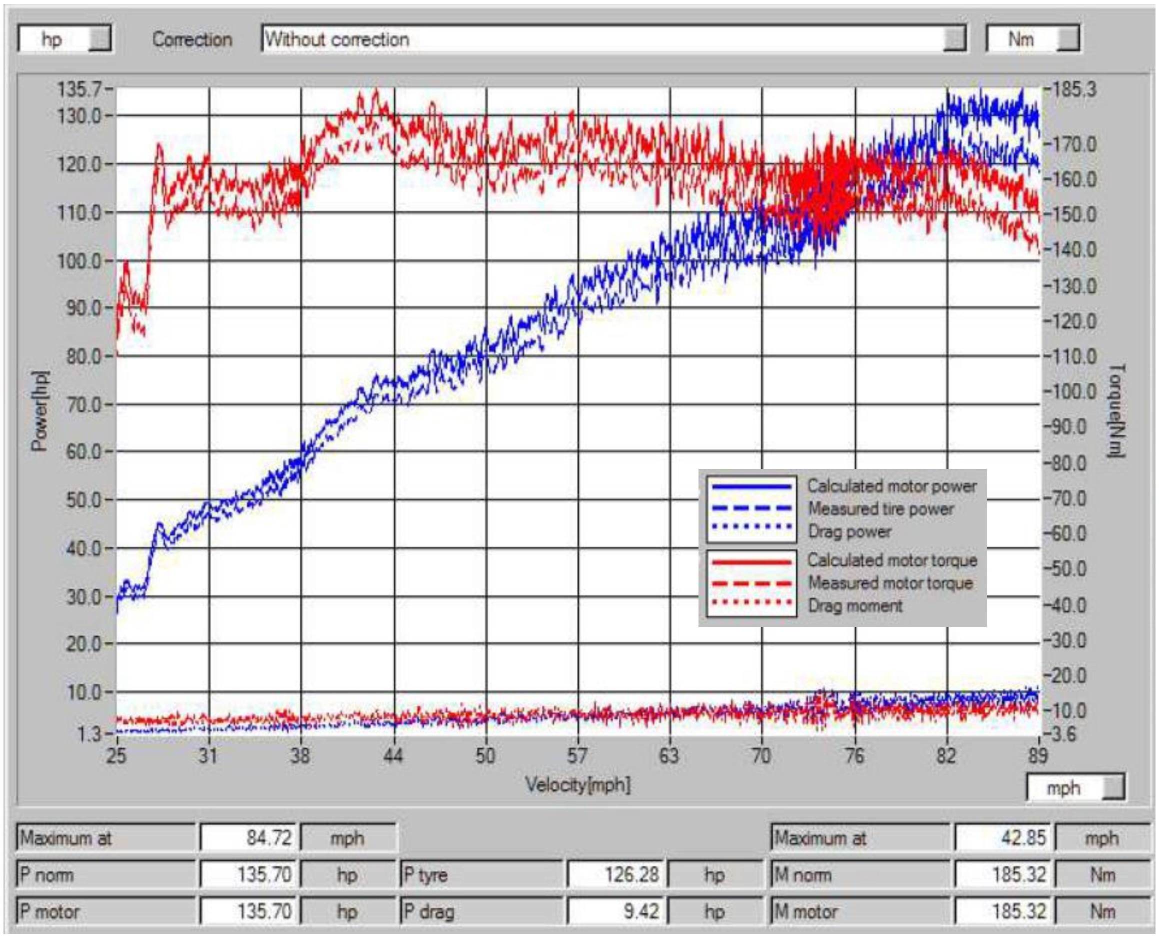


Figure 22: Maximum horsepower testing: Mazda3 2.0L with Regular

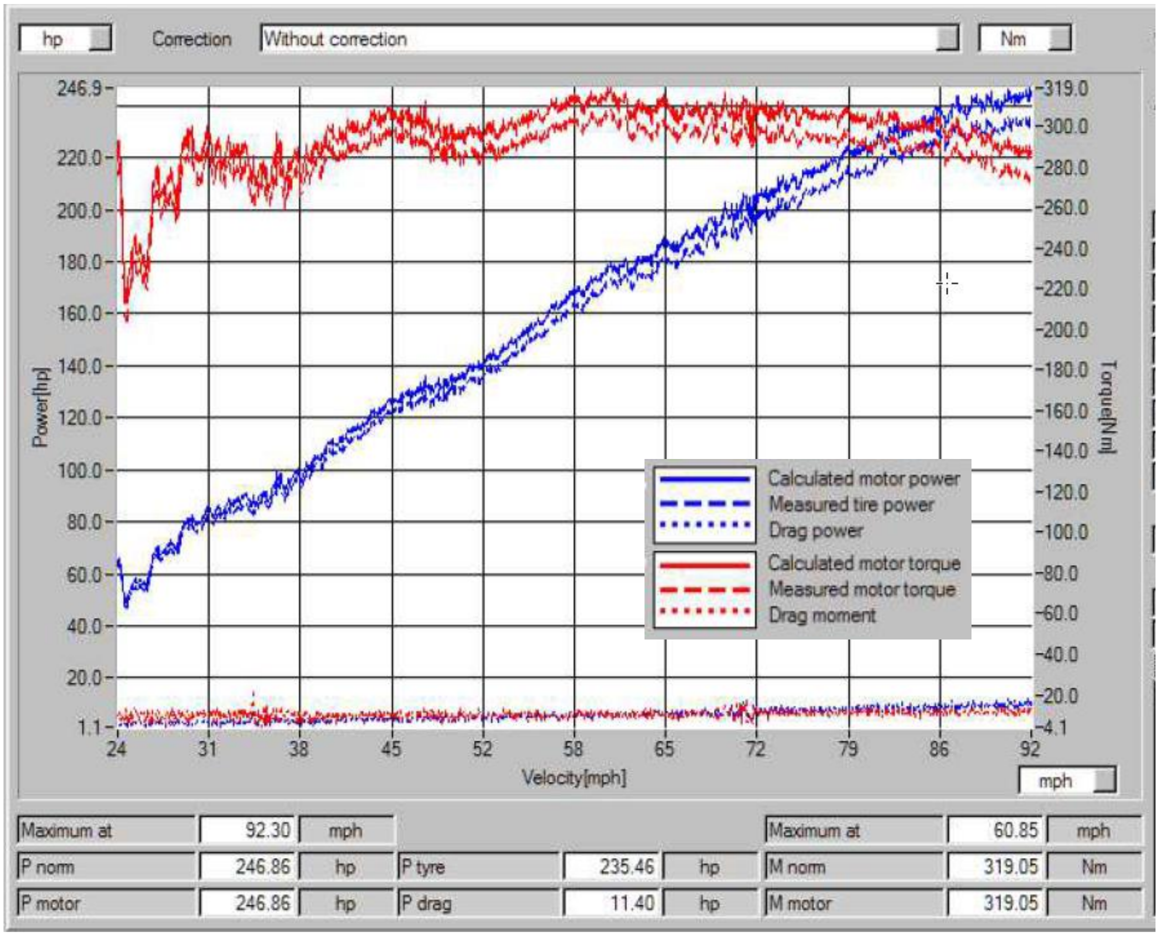


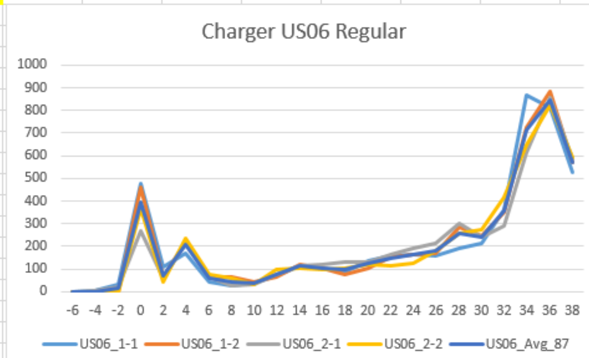
Figure 23: Maximum horsepower test: Dodge Charger 3.6L with Regular

9.7 Correlation Values for Test Data

The following table and charts represent data analysis for ignition timing data collected during four separate driving cycles of the aggressive driving test using Regular fuel on the V-6 engine test vehicle. The ignition timing data is grouped into ranges of two degrees and a correlation test performed to quantify how strongly the columns of data resemble each other. Identical columns of data have a perfect correlation of 1.0. The data in the US06 test below have correlation values ranging from 0.95 to 0.99 which indicates a very high degree of correlation. The test runs are statistically similar and are combined into an average value as shown in the column to the right and as the trace line in the lower graph.

	US06 Regular 87				
Bin	US06_1-1	US06_1-2	US06_2-1	US06_2-2	US06_Avg_87
-6	0	0	0	0	0
-4	3	0	3	0	1.5
-2	32	0	23	0	13.75
0	477	458	271	369	393.75
2	111	65	60	45	70.25
4	171	219	216	236	210.5
6	42	67	63	76	62
8	29	64	29	62	46
10	40	42	35	33	37.5
12	70	68	76	97	77.75
14	116	122	115	102	113.75
16	102	103	122	99	106.5
18	88	74	130	104	99
20	136	105	132	121	123.5
22	161	151	166	115	148.25
24	163	166	190	128	161.75
26	157	169	211	183	180
28	191	286	299	255	257.75
30	213	244	242	273	243
32	362	352	288	415	354.25
34	868	726	613	650	714.25
36	811	882	855	823	842.75
38	525	571	588	591	568.75
40	301	284	319	324	307
42	174	241	230	267	228
44	182	164	198	230	193.5
46	154	126	201	150	157.75
48	38	39	42	81	50
50	23	10	19	19	17.75
52	4	6	3	6	4.75
54	3	2	5	2	3
56	14	13	16	13	14
58	2	1	1	1	1.25
60	2	0	0	0	0.5

	Column 1	*Column 2*	*Column 3*	*Column 4*
Column 1	1			
Column 2	0.98247973	1		
Column 3	0.950385028	0.977890161	1	
Column 4	0.96507701	0.987738072	0.981520406	1



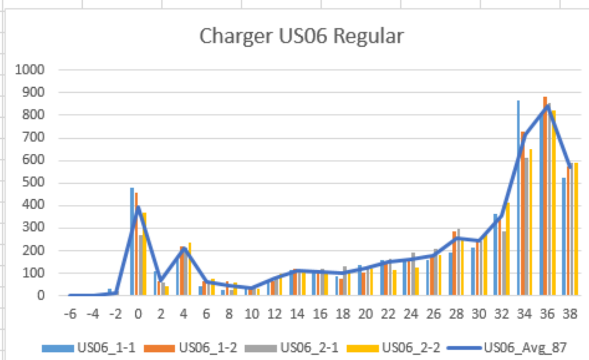


Figure 24: Correlation of four US06 driving cycles and graph showing trace of average value (bottom)

9.8 Emissions Report

Exhaust Emissions Test Report

Automobile Club Of Southern California

Automotive Research Center

2601 S Figueroa St
Los Angeles, CA 90007
Phone: (213) 741-4444
Fax: (213) 741-4670

Date:	5/11/2016	**Time:**	10:36:44
Test Legislation:	EPA		
Test Cycle:	US06+US06		
Test Purpose:	Certification		
Test Number:	GEM152_US06_US06_20160511_03		
Test Cell:	iGEMV_TC1		
Project:	AAAN-0434-003		
Manufacturer	Dodge		
Vehicle Model	Charger SXT		
Model Year	2016		
Remark:	US06 with warmup @ 75°F with Premium fuel #2		

General Data

Test Number	*GEM152_US06_US06_20160511_03*		
Test Name	*GEM152_US06_US06*		
Test Cell	*iGEMV_TC1*		
Test Type	*GEM152_US06_US06*		
Legislation	*EPA*		
Requirements (Bag)	*CERTIFICATION*		
Date	*5/11/2016*	CH_4 Response Factor	*1.186*
Test Start	*10:36:44*	Odometer Position [mi]	*13254*
Start Time Cycle	*2016-05-11 10|51-19-(000)*	Delay Time Method	*Default*
Test End	*11:12:53*		
Operator	[redacted]	Air Condition	*OFF*
Driver		Particle Measurement	*OFF*
Shifttable	*Auto*		
Flow Stream	*Bag Only*		
Calibrated Ranges	*autorange*		
Remark :	*US06 with warmup @ 75°F with Premium fuel #2*		

Vehicle Data

Manufacturer	*Dodge*	Project	*AAAN-0434-003*
Vehicle Model	*Charger SXT*	Number of Cylinders	*6*
Model Year	*2016*	Transmission	*Automatic*
VIN	*2C3CDXHG5GH126277*	Engine Configuration	*GCRXV03.65P1*
Engine Family	*GCRXV03.65P1*	License Plate	*7NVE534*
Evaporative Family	*GCRXR0145PK0*	Trim Level	*3.6L V6*
Tire Manufacturer	*Michelin*	Axle Ratio	*2.62*
Tire Model	*Primary*	Drive Axle Weight [lbs]	*4250*
Tire Size	*235/55R18*	Tank Volume [gal]	*18.5*
Tire Pressure [psi]	*32*	Tank Material	*Plastic*

Dyno Data

Inertia [lb]	*4250*	Dyno Type	***Rear Wheel Drive***
Dyno SET Coef A [lbf]	*5.144*	Street TARGET Coef A [lbf]	*44.440*
Dyno SET Coef B [lbf/mph]	*0.04222*	Street TARGET Coef B [lbf/mph]	*0.01230*
Dyno SET Coef C [lbf/mph2]	*0.015800*	Street TARGET Coef C [lbf/mph2]	*0.019630*

Fuel Data

Fuel Type	*GASOLINE*	Fuel Temperature [°C]	*15.56*
Fuel Analyze Date		Fuel Density [kg/l]	*0.7455*
Net Heat. Val. [BTU/lb]	*17897*	Carb. Weight Frac.	*0.8249*
Remarks:	*EPA Teir III EEE - Premium*		

Test Data

Test Data:	GEM152_US06_US06	Operator: Brion Lee	Speed Table	Date: 5/11/2016
Test Number:	GEM152_US06_US06_20160511_03	Driver: Ivan Ceja	Shift Table Auto	Cold Start

Vehicle		**Dyno**		**Fuel**		**Test Timing**
Vehicle Vin #	2C3CDXHG5GH126277	Inertia [lb]	4250	EPA Teir III EEE - Premium		Start Time: 10:36:44
Manufacturer	Dodge	A [lbf]	5.144	Fuel type:	GASOLINE	End Time: 11:12:53
Model	Charger SXT	B [lbf/mph]	0.04222	Density:	0.7455	
Year	2016	C [lbf/mph2]	0.015800	NHV:	17897	Soak Time[s]:
Engine Code	GCRXV03.65P1			CWF:	0.8249	
Trans	Automatic					
Odometer[mile]	13254					

Flow Stream: Bag Only

Remark: US06 with warmup @ 75°F with Premium fuel #2

Bag Analysis

PHASE 1	THC[ppmC]	CO[ppm]	CO_2[%]	NO_x[ppm]	CH_4[ppm]	NMHC[ppm]				
							Temp.[°F]	75.36	Volume[scf]	3296
Range	100	50	3	11	30		Press.[inHg]	29.82	D.F.	8.49
Zero Value	0.00	0.0	0.0	0.0	0.0		RH[%]	39.08	Ph. Start[s]	0.0
Span Value	90.29	47.50	2.490	10.108	30.393		AH[g/kg]	7.292	Ph. End[s]	606.1
Sample	2.07	16.57	1.528	0.773	0.505	1.468	Dist.[mi]	8.01	Ph. Length[s]	606.1
Mass.	0.111	1.801	2610.183	0.124	0.031	0.079	NO_x Corr. F	0.90	Bag An. Delay[s]	426
Mass per Dist.	0.0139	0.2247	325.786	0.0155	0.0039	0.0099	Dr. Viola.	0	Vio. Durat.[s]	0.0
							Crank [s]	0.0	FE [mile/gal]	26.5

Total Result

Actual	THC[g/mile]	CO[g/mile]	CO2[g/mile]	NO_x[g/mile]	CH4[g/mile]	NMHC[g/mile]	HC+NO_x[g/mile]	*Fuel Economy*	
Mass per Dist.	0.0139	0.2247	325.79	0.0155	0.0039	0.0099	0.0294	mile/gal	26.51
Mass per Dist. (rounded)	0.0139	0.2247	325.8	0.0155	0.0039	0.0099	0.0294	Dist.[mi]	8.01

CVS Data		**Cycle data**		**Environmental Data**	
Dilution Factor (Bag)	8.49	Vio. Dur.[s]	0.0	Rel. Hum.[%]	39.08
Dilution Factor (Modal)		Number	0	Ab. Hum.[g/lbs]	7.29
CVS Volume[scf]	3296.36	Act. Dist.[mi]	8.01	Pressure[inHg]	29.82
CVS Flow[scfm]	326.35			Temp.[°F]	75.36
CVS Inlet Pressure	29.06			Temp. Min.[°F]	71.78
CVS Inlet Temp.[°F]	83.63			Temp. Max.[°F]	78.80
CVS Inlet Temp. Min.[°F]	79.61			NO_X Corr. F	0.90
CVS Inlet Temp. Max.[°F]	98.86				

Bag

Concentrations	THC[ppmC]	CO[ppm]	CO_2[%]	NO_x[ppm]	CH_4[ppm]	NMHC[ppm]
Range	*100*	*50*	*3*	*11*	*30*	
Sniff	*4.294*	*16.916*	*1.577*	*0.764*	*2.270*	
Zero Value	*-0.001*	*0.016*	*0.000*	*-0.006*	*-0.005*	
Zero Offset[%]	*0.034*	*0.024*	*0.020*	*0.061*	*-0.018*	
Span Value	*90.286*	*47.499*	*2.490*	*10.108*	*30.393*	
Span Offset[%]	*-0.048*	*0.038*	*-0.066*	*-0.126*	*-0.450*	
Sample	*4.321*	*17.163*	*1.575*	*0.781*	*2.292*	*1.603*
Std. Dev.	*0.000*					
Ambient	*2.556*	*0.677*	*0.054*	*0.010*	*2.026*	
Std. Dev.	*0.000*					
Corrected	*2.067*	*16.567*	*1.528*	*0.773*	*0.505*	*1.468*
Mass	**THC[g]**	**CO[g]**	**CO_2[g]**	**NO_x[g]**	**CH_4[g]**	**NMHC[g]**
Uncorrected	*0.1113*	1.8006	2610.183	0.1241	0.0315	0.0791
Corrected	*0.1113*	1.8006	2610.183	0.1241	0.0315	0.0791
Mass per distance	**THC[g/mile]**	**CO[g/mile]**	**CO_2[g/mile]**	**NO_x[g/mile]**	**CH_4[g/mile]**	**NMHC[g/mile]**
Corrected for Lost Sample Mass	*0.0139*	*0.2247*	*325.786*	*0.0155*	*0.0039*	*0.0099*
Fuel Consumption						
Fuel Consumption[g]	*852.738*	Fuel Consumption[l/100km]		*8.871*		
Fuel Consumption[l]	*1.144*	**Fuel Economy[mile/gal]**		*26.513*		

Test Data: GEM152_US06_US06 Operator: [redacted] Date: 5/11/2016

Test Number: GEM152_US06_US06_20160511_03 Driver: [redacted]

Driver Violations

		P	Phase 1
Number of Violations	-	0	0
Duration of Violations	(s)	0.0	0.0

Number	Phase	Violation Begin (s)	Violation End (s)	Violation Duration (s)	Scheduled Speed (mph)	Max Speed Deviation (mph)
No Violations In This Test				0.0		

Test Record #: GEM152_US06_US06_20160511_03

Phase 1

Analyzer Adjust

	Range Number	Range ppm	Zero Value ppm	Zero Set Value ppm	Zero Offset %	Span Value ppm	Span Set Value ppm	Span Offset %	ReZero Value ppm
CO_2 (%)	1	3	0.00	0.00	-0.01	2.49	2.49	0.01	0.00
CO	1	50	0.02	0.00	0.03	47.50	47.50	0.00	0.00
NO_X	1	11	-0.01	0.00	-0.05	10.11	10.10	0.07	0.01
THC (ppmC1)	1	100	0.00	0.00	0.00	90.29	90.30	-0.01	0.10
CH_4	1	30	-0.01	0.00	-0.02	30.39	30.40	-0.02	0.00

Analyzer Check

	Range Number	Range ppm	Zero Value ppm	Zero Set Value ppm	Zero Drift %	Span Value ppm	Span Set Value ppm	Span Drift %	2% Drift Validation
CO_2 (%)	1	3	0.00	0.00	-0.08	2.49	2.49	-0.08	
CO	1	50	0.01	0.00	0.02	47.52	47.50	0.04	
NO_X	1	11	0.01	0.00	-0.02	10.09	10.10	-0.20	
THC (ppmC1)	1	100	0.03	0.00	-0.07	90.25	90.30	-0.03	
CH_4	1	30	-0.01	0.00	0.00	30.26	30.40	-0.43	
N2O				0.00					

Validation

Phase 1

Test Record #: GEM152_US06_US06_20160511_03 — Vehicle ID: 2C3CDXHG5GH126277

		Average	Min	Max	Low Limit	Upper Limit	Status
Phase 1							
Cell Temperature	(°F)	75.36	71.78	78.80	68.00	86.00	Passed
Barometer	(inHg)	29.82	29.82	29.82	26.58	32.48	Passed
Dew Point Temperature	(°F)	48.67	46.22	51.26			
Phase 1							
Dilution Air Concentrations							
HC	(ppm)	2.56			0.00	9.00	Passed
NO_x	(ppm)	0.01			0	1.50	Passed
CO	(ppm)	0.68			0	12.20	Passed
CO_2	(%)	0.05			0.00	0.09	Passed
CH_4	(ppm)	2.03			0.00	12.20	Passed
N2O	(ppm)				0.00	1.00	
Bag Analysis Time	(s)	363.90				1200	Passed
Bag Analysis Time	(s)	425.9				1200	Passed
Bag Sample Proportionality Check							
Condensation Potential							
Test-Cycle Specific Validations							
Phase Distance	(miles)	8.01			7.81	8.21	Passed
Sample Phase Time	(s)	606.1					
Duration Phase 1	(s)	606.10					
Crank Time Phase1	(s)	0.0000				5	Not App
Crank Counts		0				1	Passed
Hot Soak Time	(s)				540.00	660.00	
Test Hold Counts		0					
Duration Test Hold	(s)	0.00				60	Passed
Bag Calibration Sequence							Passed
CVS Choke Flow Conditions							Passed

9.9 Dollars Wasted Annually on Premium Fuel

U.S. drivers waste **$2.1 billion** annually by putting Premium gasoline into vehicles designed to run on Regular.

AAA performed a survey of consumers (Premium Fuel Omnibus Survey, Project #160042) in August 2016. The results are summarized as follows:

- Seven in 10 (70%) U.S. drivers have vehicles that require Regular gasoline according to the manufacturer, while 10% have vehicles that require Mid-grade gasoline and 16% have vehicles that require Premium gasoline. The remaining 4% have vehicles that don't use gasoline.
- While nine in ten (89%) US drivers with vehicles that require Regular gasoline haven't upgraded to Premium in the past 12 weeks, 11% upgraded to Premium at least once. That means 16.5 million[9] U.S. drivers unnecessarily used Premium-grade gasoline in their vehicle.
- On average, those who upgraded to Premium did so four (4) times in the past 12 weeks – or at least once per month.
- In total, U.S. drivers unnecessarily upgraded from Regular to Premium gasoline an estimated 272 million times in the past year[10].

Previous survey results from the Fuels Institute indicated that a majority of drivers fill up their vehicles gas tanks before the "low fuel" warning illuminates. This does not translate into a specific number of gallons left in the tank when filling; 90% of fuel tank volume is used in calculations to reflect this consumer practice.

The fuel tank volume used in calculations is 17.75 gallons. The Toyota Camry is one of the most popular cars on the road today and has been for many years. The vehicle, like most automotive models, has grown in physical size over the years while achieving improved fuel economy. The gas tank volume of the 1996 Camry is 18.5 gallons; the 2016 Camry holds 17 gallons of gasoline. Averaging the two volumes yields the value of 17.75 gallons used in calculations.

AAA research found a nationwide average difference of 49.33 cents in the cost per gallon of Premium and Regular gasoline. (Refer to Section 10.1 "Average Gasoline Prices" for additional information.)

Count of fill-ups where Premium used instead of Regular		Percent of tank volume		Average tank gallons		Additional cost for Premium gasoline		**Dollars wasted annually on Premium**
271,887,000	X	90%	X	17.75 gallons[11]	X	49.33 cents[12]	=	$2,142,596,667

[9] 214 million licensed drivers (as of 2014, according to the Federal Highway Administration) * 70% who have vehicles that require Regular gasoline * 11% who upgraded from Regular to Premium gasoline in the past 12 weeks = 16,478,000 drivers who needlessly used Premium fuel

[10] 16,478,000 drivers * an average of 16.5 upgrades per year (3.8 upgrades in the past 12 weeks / 12 *52 weeks per year) = 271,887,000

[11] 90% x 17.75 = 15.975 gallons per fill up. This is the value used in the "Dollars Wasted" calculation.

[12] Refer to Appendix 10.1 for more detail. Additional cost for Premium gasoline is a daily average from 8/27/2015 to 8/26/2016.