



AAA PREMIUM FUEL RESEARCH, PHASE II:

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



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Abstract

The primary research questions and key findings are shown below.

Primary Research Questions:

1. If a vehicle is labeled premium recommended, does using premium gasoline result in improved fuel economy?
2. If a vehicle is labeled premium recommended, does using premium gasoline result in increased performance (horsepower)?
3. What is the difference in retail cost between premium and regular gasoline?

Key Findings:

1. Most vehicles tested showed a modest improvement in fuel economy.

AAA test vehicles averaged 2.7% improvement in fuel economy during testing (not directly comparable to an EPA estimate for MPG). Individual vehicle test result averages ranged from a decrease of 1.0% to an improvement of 7.1%.

Vehicle	Average MPG Improvement* using Premium
Ford F150	5.0%
Cadillac Escalade	7.1%
Mazda Miata	0.7%
Audi A3	-1.0%
Ford Mustang	2.3%
Jeep Renegade	1.9%
Average Results	2.7%

** Average fuel economy improvement is limited to test conditions and not directly comparable to real world driving.*

Figure 1: Average MPG Improvement Using Premium Gasoline

2. Most vehicles tested showed a modest improvement in performance.

AAA test vehicles averaged an increase in horsepower of 1.4% across AAA's tests. Individual vehicle test result averages ranged from a decrease of 0.3% to an improvement of 3.2%.



Vehicle	Average Horsepower* Improvement using Premium
Ford F150	2.1%
Cadillac Escalade	0.7%
Mazda Miata	0.8%
Audi A3	2.1%
Ford Mustang	3.2%
Jeep Renegade	-0.3%
Average Results	1.4%

**Horsepower improvement shown is average of AAA tests.*

Figure 2: Average Horsepower Results Using Premium Gasoline

- Using national averages, the difference in retail cost between regular and premium gasoline is approximately 20% to 25%, or 50 cents per gallon.

Following more than ten years with a seemingly inelastic price differential of 10% for premium gasoline, the cost of premium has risen steadily since 2010. The price differential for premium peaked near 30% in 2016 and has since remained in the 20% to 25% range.

The fuel economy improvements recorded during AAA testing do not offset the potential extra cost to purchase premium gasoline.



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AAA Premium Fuel Research – Phase II

3 Overview

Which fuel should a driver select for a vehicle that recommends the use of premium gasoline?

Gasoline-powered cars and light trucks are typically labeled at the fuel door or cap with the octane rating that is recommended or required for use in the vehicle:



Figure 3: Fuel selection options

1. **Regular Unleaded** → Manufacturer recommends the use of regular unleaded gasoline with a (R+M)/2 octane rating of 87. Opting for premium gasoline does not produce any quantitative benefit for the consumer in terms of horsepower production or fuel economy. Refer to previous AAA Research¹, [AAA Premium Fuel Research: Proprietary research into the use of premium octane gasoline when not required by the manufacturer](#)
2. **Premium Recommended** → Manufacturer recommends the use of 91 octane or higher premium gasoline. The results of this research report are that vehicles labeled premium recommended *may* see some benefit in terms of fuel economy or horsepower when using premium gasoline.
3. **Premium Required** → Manufacturer requires the use of 91 octane or higher premium gasoline. In this case, the vehicle manufacturer provided clear instruction and consumers should always use premium gasoline. Failure to use premium could potentially cause engine damage that might not be covered by the manufacturer's warranty.

If your vehicle is one labeled premium recommended², the decision of which grade gasoline to purchase is not complicated, but there are considerations to be aware of – to be economical, environmentally friendly, and to get the best possible performance from your automobile. Automakers use a variety of phrasing in owner's manuals to communicate the reasons why premium gasoline is recommended. See Appendix §13.1 for examples.

Will something bad happen if regular (87 octane) gasoline is used in a premium recommended car?

¹ <http://newsroom.aaa.com/2016/09/u-s-drivers-waste-2-1-billion-annually-premium-gasoline/>

² Refer to the Appendix §13.3 for a list of vehicles that are labeled Premium Recommended as verified through the owner's manuals. This list is not comprehensive.



Does your vehicle knock or ping under load when using regular gas? If so, then the necessary action is to increase the octane of the gasoline you purchase (step up from regular to mid-grade to premium) until the pinging is no longer audible. It could be that the engine is under a greater load than realized, and in response, the engine management system is looking for that higher octane. Over time, knocking can cause engine damage. For further information on knocking, refer to Terminology in the Appendix §13.2.

Without any noticeable knocking or pinging when using regular gasoline, the answer is “no” – but do not select gasoline that is lower than 87 octane. Vehicles labeled premium recommended can safely use regular gasoline (87 octane) with no adverse effects. According to owner’s manuals (and the content varies considerably), using regular gasoline may result in decreased fuel economy or lower performance. It is important to note that lower octane gasoline (85 octane) is available in some mountain states in the western United States. AAA researchers found multiple owner’s manuals (vehicles that are premium recommended) that specified no lower than 87 octane when using regular gasoline. Motorists should consult the owner’s manual for their specific vehicle for the most complete information on selecting between available grades of gasoline.

To address these concerns, AAA tested fuel economy and horsepower production.

To examine the differences in fuel economy when using regular versus premium gasoline in premium recommended vehicles, AAA researchers developed a chassis dynamometer test to simulate driving on flat and increasingly steep grades. The steeper grades resulted in more work for the test vehicles’ engines, and conditions where the higher octane in premium gasoline might be advantageous. Vehicle emissions were measured during these tests and fuel economy was calculated from the emissions content.

Researchers then used the chassis dynamometer to measure static (vehicle speed does not change) and dynamic (typical horsepower test with vehicle accelerating to maximum rpm) horsepower produced by test vehicles when fueled with regular gasoline and again with premium gasoline.

4 Technology Description

4.1 Engine Calibration

Gasoline engines in modern automobiles and light trucks are able to react to a wide range of variables and continue to provide lower emissions, higher fuel economy and improved drive quality – objectives that are often seemingly at odds. Inputs to a vehicle’s engine management computer include sensors that measure the quantity of air used (MAF – mass air flow sensor), electronic fuel injectors that can provide precise – even multiple – deliveries of gasoline to individual cylinders during each engine rotation, and multiple oxygen sensors in the vehicle



exhaust to provide feedback on how efficiently each cylinder of gasoline and air was burned by the engine. Engine calibration is a complex topic. There is a vast amount of data traveling at high speed and an almost infinite number of adjustments commanded by the vehicle's engine management computer. Vehicle manufacturers employ different engine management strategies, and testing and calibration has resulted in a recommendation for premium gasoline for some vehicles. Manufacturers produce vehicle models to be driven by motorists throughout the United States. These motorists have different vehicle uses, commutes, road conditions, passenger numbers, etc. While the manufacturer is not requiring the use of premium gasoline, it is making the recommendation and leaving the choice up to the vehicle's owner.

Research that quantifies how a vehicle reacts to gasoline with different octane ratings is essentially looking at engine calibration – the programming done by the vehicle's manufacturer to provide low emissions, high fuel economy, and maximum driving performance. Higher octane ratings are achieved by additives to gasoline that allow higher compression before the gas-air mixture in a combustion cylinder “auto-ignites.” This auto-ignition causes an audible knock or ping sound – particularly on hard acceleration or during a hill climb. Higher octane allows more power extraction before auto-ignition occurs, thus allowing an engine design that uses a higher compression ratio and or operating the engine with ignition timing further advanced. When the engine design and fuel requirements are closely matched, maximum operating efficiency can be obtained. For the consumer, this means better performance and fuel economy.

To complicate the engine calibration challenge, automakers cannot rigidly enforce the octane level and quality of gasoline used in the vehicles they produce. Fuel quality varies by region across the United States. Drivers can freely select from 85 octane regular to super-premium 94 octane (or higher) depending on the area of the country and fuel retailer. Knowing what octane gasoline is recommended or required by your vehicle can help maximize both fuel economy and performance. Consult the owner's manual for the most accurate information – including limitations on the use of low-octane regular gasoline.

4.2 Test Vehicles

AAA Researchers initially identified vehicles labeled by the manufacturer as premium recommended.³ These vehicles were then grouped by fuel injection system and induction type. Researchers selected vehicles to represent a wide variety of vehicle types, fuel-delivery systems, and naturally aspirated/turbocharged engines.

³ See Appendix §13.3 for a list of vehicles that recommend premium gasoline.

5 Vehicles Selected for Testing

The final selection of test vehicles for the “AAA Premium Fuel Research – Phase II”:

Model Year	Make	Model	Drive Axle	Transmission	Engine Layout	Engine Displacement	Air Induction (Aspiration)	Fuel Delivery System
2017	Ford	F150 XLT	RWD	10-speed auto	V6	3.5L	Turbo	GDI+PFI
2016	Cadillac	Escalade ESV	RWD	8-speed auto	V8	6.2L	NA	GDI
2015	Mazda	MX-5 Miata	RWD	5-speed manual	I4	2.0L	NA	PFI
2016	Audi	A3	FWD	6-speed dual clutch	I4	1.8L	Turbo	GDI
2017	Ford	Mustang GT	RWD	6-speed auto	V8	5.0L	NA	PFI
2016	Jeep	Renegade	FWD	6-speed manual	I4	1.4L	Turbo	PFI

Figure 4: Test Vehicles - Final Selection and Attributes

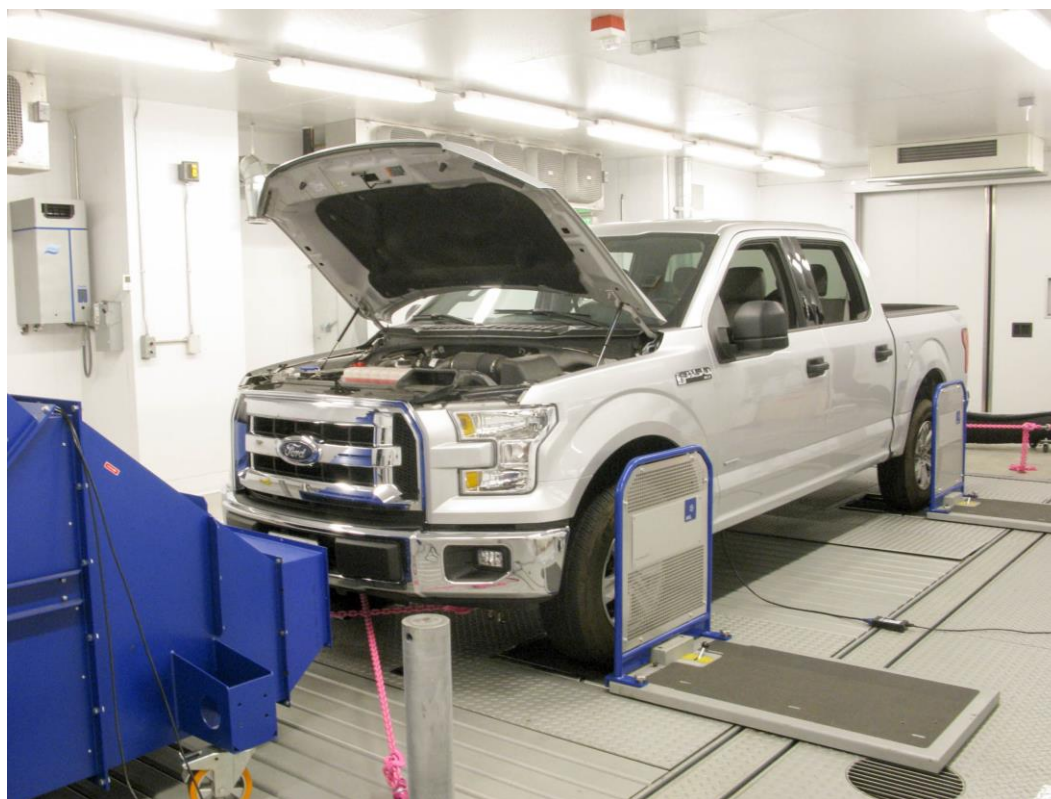


Figure 5: 2017 Ford F150 on Dynamometer

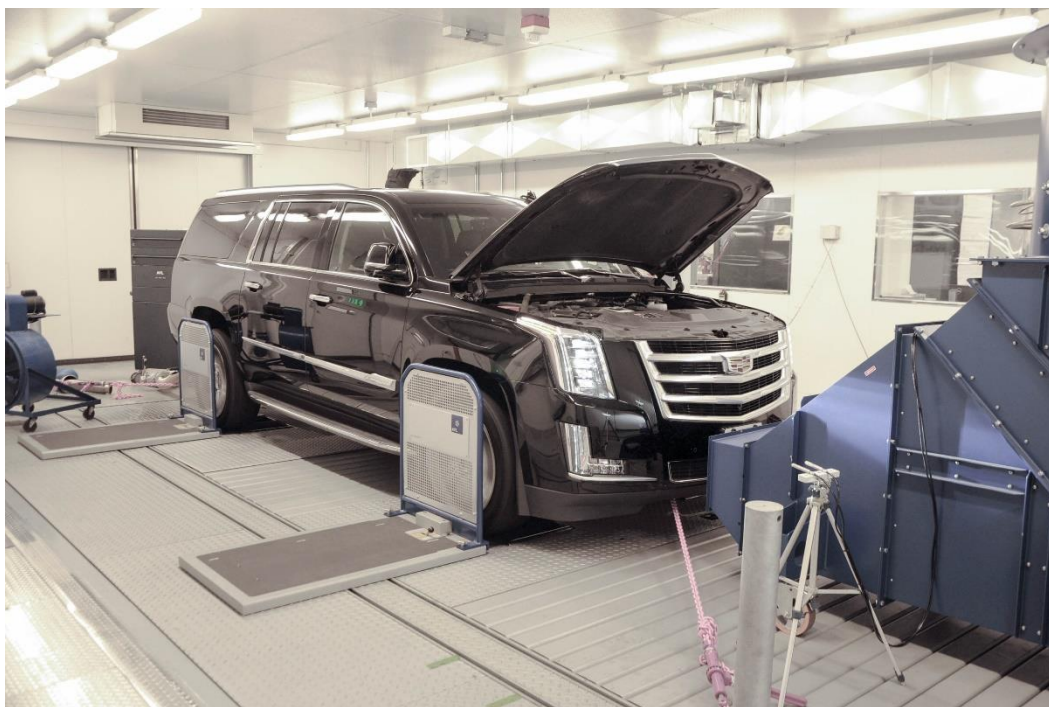


Figure 6: 2016 Cadillac Escalade ESV on Dynamometer



Figure 7: 2015 Mazda Miata on Dynamometer

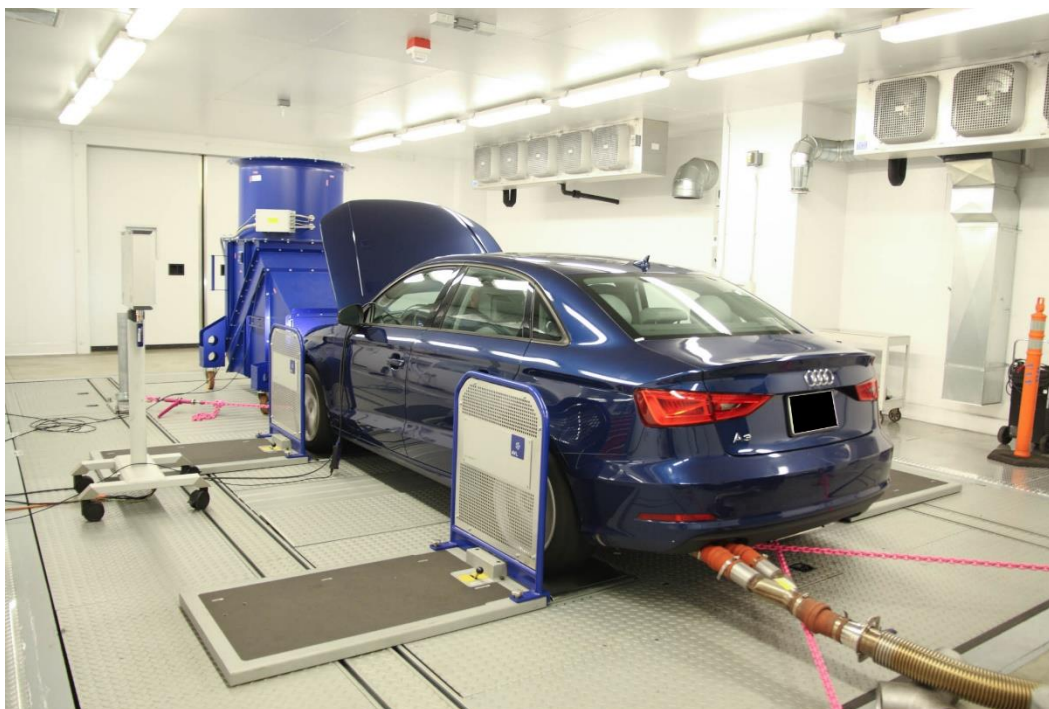


Figure 8: 2016 Audi A3 on Dynamometer



Figure 9: 2017 Ford Mustang GT on Dynamometer

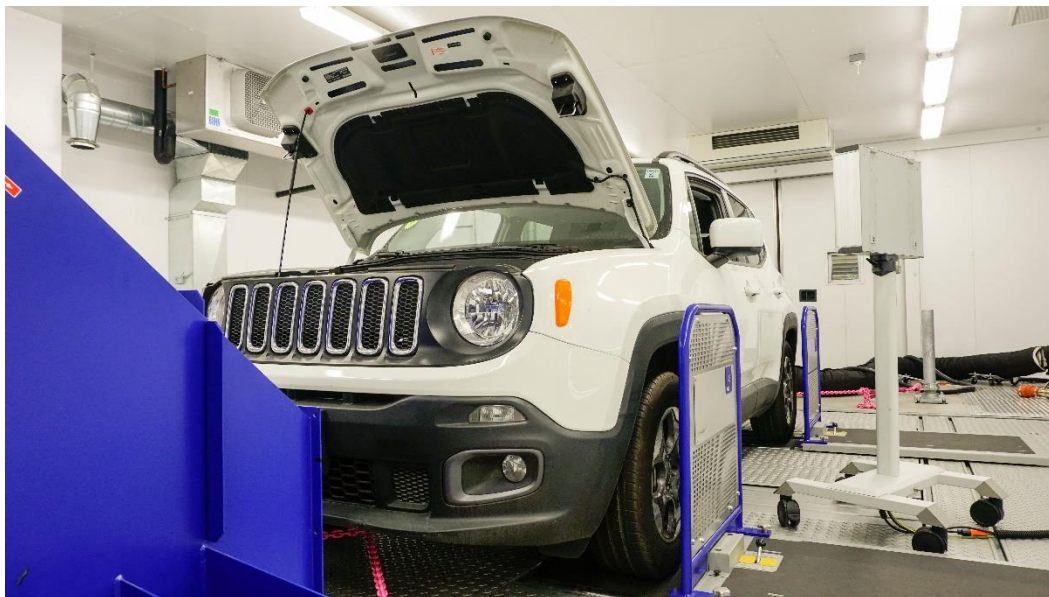


Figure 10: 2016 Jeep Renegade on Dynamometer



5.1 Vehicle Selection Methodology

Vehicle selection criteria were developed as described below.

1. The first criteria for vehicle selection was to include only those vehicles where the manufacturer *recommends* but does not *require* the use of premium gasoline. Vehicle registration data was used as a starting point in identifying these vehicles, and researchers verified the classification of recommended fuel using vehicles owner's manuals.
2. The vehicle's use of gasoline with higher octane rating is the focus of the test. Engine configuration and displacement, fuel delivery system, and air induction method are primary differences in classifying automotive engines.
3. There are a variety of engine technology combinations present in the vehicle fleet currently on the road and available for sale. This project specifically focused on fuel delivery and air induction. The goal was to select vehicles with different combinations of these technologies
 - a. Groupings were established to divide the fuel delivery system into two groups. The first, (Port Fuel Injection or PFI) includes all configurations of fuel injectors that deliver an atomized fuel spray behind the intake valves in the intake manifold ports. The second grouping is direct fuel injection (Gasoline Direct Injection or GDI) where atomized fuel is sprayed directly into the combustion chamber.
 - b. Groupings were established to divide the air induction system into two groups. The first, boosted, includes all variations of forced air induction: turbochargers, superchargers, variable-geometry turbos, twin-turbos, and the combination of turbocharger and supercharger. The second grouping is naturally aspirated engines where air is pulled into the combustion chamber solely by the action of the receding piston.
4. Researchers desired to have a test fleet that was both representative of vehicles that recommend the use of premium gasoline and was sufficiently varied in body style to facilitate personal identification by our target audience. In other words, readers of the report are likely to see at least one of the vehicles tested as being substantially similar to what they drive.
5. Vehicle registration data was used to research the number of vehicles on road (VOR) for each vehicle manufacturer/make/model/trim level/engine/induction system that was identified to recommend the use of premium gasoline. Vehicle models with the highest

VOR count were given priority if multiple models met a combination of the above qualifications.

6. Further refinement of the vehicle list occurred as specific vehicles were examined for availability (from all available sources), and suitability for dynamometer testing (vehicles needed to either be available in a manual transmission, or be equipped with an automatic transmission having manual gear selection (i.e. paddle shifters)).
7. The final vehicle selection addresses both fuel delivery groups, both air induction types, five different vehicle manufacturers and six different vehicle segment types.

	Fuel Delivery	Induction	Displacement	Make	Model	Segment
Group 1	<i>PFI</i>	<i>Naturally aspirated</i>	<i>5.0 liter, 8 cylinder</i>	Ford	Mustang GT	<i>Performance/muscle car</i>
Group 2	<i>PFI</i>	<i>Boosted</i>	<i>1.4 liter, 4 cylinder</i>	Jeep	Renegade	<i>Compact CUV</i>
Group 1	<i>PFI</i>	<i>Naturally aspirated</i>	<i>2.0 liter, 4 cylinder</i>	Mazda	MX-5 Miata	<i>Sports car</i>
Group 3	<i>GDI</i>	<i>Naturally aspirated</i>	<i>6.2 liter, 8 cylinder</i>	Cadillac	Escalade ESV	<i>Full-size SUV</i>
Group 4	<i>GDI</i>	<i>Boosted</i>	<i>1.8 liter, 4 cylinder</i>	Audi	A-3	<i>Mid-size sedan</i>
Group 4	<i>GDI (+PFI)</i>	<i>Boosted</i>	<i>3.5 liter, 6 cylinder</i>	Ford	F150 XLT	<i>Full-size pickup</i>

Figure 11: Test Vehicles

6 Test Equipment and Resources

The Automobile Club of Southern California performed all laboratory and on-road testing at and around the Automotive Research Center located in Los Angeles, California.

6.1 Test Fuel

AAA researchers used EPA Tier 3 certification test fuel with 10% ethanol content in both regular 87 octane and premium 93 octane ((R+M)/2 method) varieties. The two batches chosen were closely matched on energy content (net heat of combustion) in order to better isolate the effects of higher octane ratings on fuel economy. Fuel analysis reports on both test fuels are available in the Appendix §13.4.

6.2 Dynamometer

The Automotive Research Center uses a pair of AVL 48-inch diameter electric chassis dynamometers in order to test front-, rear, and all-wheel-drive vehicles. The front dynamometer is designed for light-duty vehicles and is rated for 150 kW while the rear dynamometer can handle up to medium-duty vehicles and is rated for 220 kW. The dynamometer is used to simulate the same tractive forces that a vehicle encounters when it is driven on the road. The dynamometers are capable of simulating a road grade, which was crucial for this experiment. When a new vehicle is first put on the chassis dynamometer, a road-load derivation is performed to match the dynamometer to the real-world forces, which are unique for each vehicle. The dynamometers are also capable of measuring a vehicle's horsepower and torque, which does not require any sort of road-load simulation.



Figure 12: Dynamometer in motion

The dynamometer is located inside of a temperature and humidity-controlled environmental chamber. While capable of extreme temperatures (20°F to 95°F), standard 75°F testing was used for this project.

6.3 Emissions Measurement Equipment

Vehicle emissions are measured with an AVL i60 Series II Constant Volume Sampler (CVS) and emissions bench, capable of measuring very low emission levels. The vehicle exhaust pipe is connected to a mixing unit where fresh air is used to dilute the exhaust. The CVS blower pulls the diluted exhaust through heated lines and calibrated venturis to maintain constant flow and avoid condensation. A small portion of the diluted exhaust is stored in sample bags and is later analyzed by the emissions bench. The emissions bench measures hydrocarbons, oxides of nitrogen, carbon monoxide, and carbon dioxide, then calculates fuel economy based on the carbon balance and the distance traveled.

6.4 Data Logger and Sensors

For this project, AAA researchers used a laptop-based OBD-II scan tool. The software, Silver Scan Tool®, developed by RA Consulting, is capable of logging any number of generic OBD-II parameters. The hardware interface to the vehicle is a Dearborn Group DPA5. For this project, parameters related to engine operation were logged such as engine load, intake manifold pressure, engine rpm, vehicle speed, ignition timing, mass air flow, fuel rail pressure, and modeled catalyst temperature.

7 Inquiry #1: If a vehicle is labeled *premium recommended*, does using premium gasoline result in improved fuel economy?

7.1 Objective

Perform quantitative testing under increasing engine load ranges to determine fuel economy using first regular and then premium octane gasoline. The testing is performed under increasing engine load because higher octane in premium gasoline helps to prevent auto-ignition under high engine load conditions.

7.2 Methodology

The chassis dynamometer is used to simulate driving on a level road and up increasing grades. The specific amount of work done by each vehicle is different, but the task (e.g., driving up a hill at a steady 65 mph) is consistent across all vehicles tested. Test sampling periods of 180 seconds follow a warmup and stabilization period at each of the following simulated road grades: 0%, 2%, 4%, and 6%.

The concept of road grade can be confusing. A 100% grade is a road that is at a 45° angle above horizontal.

To calculate a road grade, civil engineers divide the “rise” by the “run”.

Road grade percent is the tangent of the angle of the roadway compared to horizontal. AAA researchers included road testing in Echo Park, California (suburb of Los Angeles) on roads with 35% grade – the second steepest in California. The purpose of this portion of the road test was to determine if vehicles exhibited knocking (auto-ignition) under heavy load at low speeds – on regular or premium gasoline. Highway driving up moderate grades of 2-3% evaluated the presence of knocking at higher speeds.

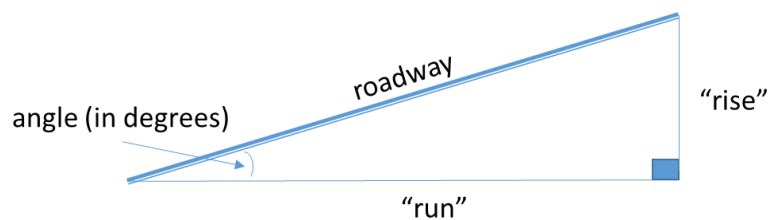


Figure 13: Calculation of Road Grade Percent



Vehicle emissions analysis provided accurate fuel economy results for each test run. Multiple runs at each combination of octane and grade were performed and the results averaged. The tests performed are not the same as used to generate EPA fuel economy ratings.

7.2.1 On Board Diagnostic Data

The OBD data analysis (Appendix §13.8) gives insight into the varying strategies used by the different manufacturers. While this study focused on fuel economy and performance, since that is what the majority of motorists are most interested in, the data shows that the engine management systems of the vehicles tested did adjust to the two different octane fuels. For the specific test points (vehicle, speed, grade) that showed the largest difference in fuel economy, there was a corresponding large difference in ignition timing. The engine management was able to advance the spark timing more on premium gasoline. In turn, the engine needed less air (lower MAP or MAF) to do the same amount of work, resulting in improved fuel economy. Many of the test points show small differences in ignition timing and MAP/MAF data, and correspondingly, only a small change in fuel economy. Refer to Appendix §13.8 for graphs of mass air flow (for naturally aspirated test vehicles), intake manifold absolute pressure (for boosted test vehicles), ignition timing, and modeled catalyst temperature for all test vehicles.

7.2.2 Simulated Road Grade Testing with Emissions Analysis (MPG)

The simulated road grade test is comparable to the following real world driving situations. All test conditions are on simulated level terrain or “up hill” as the added engine load is where fuel with higher octane can be advantageous.

- **0% grade** represents driving at a constant 65 mph (cruise control engaged) on an Interstate highway that travels through flat, level ground
- **2% grade & 4% grade** represent driving at a constant 65 mph (cruise control engaged) on increasing levels of incline
- **6% grade** represents driving at a constant 55 mph⁴ (cruise control engaged) on an Interstate highway that climbs a long, steep grade

The road grade simulations were used to provide increasing engine loads on the vehicle. A typical “load” could be a vehicle packed with luggage, at capacity with passengers, or towing a trailer.

7.2.3 Test Procedure

Vehicles were inspected for compliance with necessary equipment, odometer min/max, tire size and condition, etc. During road testing, the vehicles were checked for normal driving (no

⁴ Speed on the 6% grade was reduced to 55 mph to work within limits of constant volume sampling (CVS) emissions test equipment.



pulling side-to-side – imperative for 4WD dynamometer testing), and the presence of knocking/pinging under load. Vehicles were photo-documented for overall condition and specifications, including the under hood Vehicle Emissions Compliance Information (VECI) label, VIN, etc. Multiple checks were performed to confirm vehicle suitability for the test, including inspection to confirm no fluid leaks, a review of the manufacturer's technical service bulletins (TSBs), and a number of preliminary tests on the dynamometer. The dynamometer checks optimized vehicle hold-down security, determined start and end speeds for dynamic horsepower testing, and verified that the 4-bag emissions testing worked properly. A simplified vehicle acceptance checklist is in the Appendix §13.5.

7.3 Fuel Economy Results

Fuel economy measured at different engine loads and using both regular and premium gasoline are tabulated below. It is important to note that each individual test is not representative of fuel economy a driver would observe in real-world driving conditions. Acceleration, deceleration, coasting, and starting from a full stop are all normal aspects of driving, but are not included in the specific test segments.

Vehicle	AAA Research Results Dyno and Emissions Testing on Simulated Incline								
	0% grade flat terrain @ 65mph		2% grade moderate hill @ 65mph		4% grade moderate hill @ 65mph		6% grade steep hill @ 55mph		Average MPG Improvement When Using Premium
Ford F150	21.35	21.39 0.2%	14.30	14.91 4.3%	10.10	10.87 7.7%	9.29	10.01 7.8%	5.0%
Cadillac Escalade	23.27	26.41 13.5%	17.25	17.60 2.0%	11.65	12.81 9.9%	10.73	11.02 2.7%	7.1%
Mazda Miata	32.29	32.58 0.9%	24.99	25.23 1.0%	20.39	20.59 0.9%	18.41	18.43 0.1%	0.7%
Audi A3	37.59	36.73 -2.3%	26.34	25.75 -2.2%	19.80	19.83 0.1%	17.14	17.20 0.3%	-1.0%
Ford Mustang	26.60	26.68 0.3%	20.06	20.07 0.1%	15.83	15.98 1.0%	12.91	13.94 8.0%	2.3%
Jeep Renegade	35.88	36.71 2.3%	25.40	25.71 1.2%	17.95	18.47 2.9%	14.72	14.90 1.2%	1.9%

Figure 14: Summary Chart of MPG Results Regular vs. Premium Gasoline

Five out of the six vehicles achieved better fuel economy using premium gasoline while driving on all grade simulations. The varying differences in fuel economy represent the different engine management strategies by the vehicle manufacturers.



The F150 demonstrated consistent improvement in fuel efficiency as the simulated road grade increased. The average improvement of 5% is considerable – but may not be enough to create a positive ROI depending on the additional cost of premium gasoline in your area⁵. Additional considerations regarding vehicle loading should be part of the decision on which fuel grade to select.

The Cadillac Escalade engine is equipped with cylinder deactivation and operated as a 4-cylinder during the 0% grade simulation. The Escalade recorded the highest benefit to using premium gasoline during the 0% grade simulation. The three subsequent grades (2%, 4%, and 6%) were accomplished with the full V-8 configuration (cylinder deactivation not active). There is no driver control for cylinder deactivation on this vehicle – the vehicle itself determines how many of its cylinders need to be running at any given time.

The vehicles that experienced the greatest gain in fuel economy on premium were the heaviest vehicles, the full-size pickup and full-size SUV. The Escalade had the largest increase when running in cylinder deactivation mode, while the F150 had a smaller displacement than the Escalade overall. In other words, premium gasoline was most beneficial when a small displacement engine is being used to move a large amount of weight⁶.

During road testing, the Audi A3 had audible engine knock in road driving on a severe grade at low speed when using regular gasoline. This supports using premium gasoline in the A3 at all times. Refer to Summary Recommendations in section 10.

Vehicle	EPA Combined MPG	Average MPG Improvement When Using Premium	Adjusted MPG when using Premium	Regular	Premium	Annual Cost to use Premium	Adjusted Cost to use Premium (mpg change)
Ford F150	21	5.0%	22.0	\$1,749	\$2,096	\$347	\$248
Cadillac Escalade	17	7.1%	18.2	\$2,161	\$2,590	\$429	\$258
Mazda Miata	24	0.7%	24.2	\$1,531	\$1,834	\$304	\$291
Audi A3	27	-1.0%	26.7	\$1,361	\$1,631	\$270	\$287
Ford Mustang	18	2.3%	18.4	\$2,041	\$2,446	\$405	\$349
Jeep Renegade	26	1.9%	26.5	\$1,413	\$1,693	\$280	\$249

Figure 15: Annual Fuel Cost Comparison

⁵ Refer to §9.3; national average for premium gasoline is 20% to 25% higher than the cost of regular gasoline since late 2016.

⁶ The characteristic described is a high vehicle mass to engine displacement ratio or load factor.



Figure 13 compares annual fuel costs based on driving 15,000 miles per year and using U.S. National Average prices for regular and premium gasoline⁷. Fuel economy ratings used in these calculations are the EPA combined highway/city ratings for each of the test vehicles.⁸ Appendix §13.9 provides an explanation of the calculations.

8 Inquiry #2: If a vehicle is labeled *premium recommended*, does using premium gasoline result in increased performance (horsepower)?

8.1 Objective

Determine if a vehicle performs better on premium gasoline by measuring horsepower produced under controlled conditions.

8.2 Methodology

Two tests for horsepower were implemented.

8.2.1 Static Horsepower Measurement

This type of vehicle power measurement test can only be done on chassis dynamometers capable of absorbing power. The test is set up by calculating the wheel speed (in the same transmission gear as the dynamic power tests are performed) that equates to 2000 and 4000 rpm. The dynamometer is set to the desired roll speed, and provides the necessary rolling resistance to maintain that speed. The dynamometer provides power to the vehicle if the driver is in neutral or in gear and off the gas. In this case, the vehicle is effectively coasting. As the driver begins to depress accelerator pedal, the dynamometer then starts to absorb the power the vehicle is providing. Because most engines are capable of producing more power momentarily than they can sustain over time, this type of test shows the power drop over time as the engine and associated components heat up. The 2000 and 4000 rpm points were chosen to highlight potential differences between regular and premium gasoline in the low to mid-RPM range where an engine tends to be more knock-limited.

For example: The Miata had 24.1 inch diameter tires, a 4.10:1 axle ratio, and a 3rd gear ratio of 1.33:1. The car was put into neutral and the dynamometer was brought up to 25 mph. The car was then put into 3rd gear, which gave an engine speed of 2000 RPM. The dynamometer and OBD data loggers were started and the driver floored the accelerator pedal. The dynamometer speed did not change and maintained the 25 mph set point, thus holding the vehicle at 2000 RPM. The test ran for approximately 25 seconds. The dynamometer data logger then provides a log of power over time.

⁷ Source is GasPrices.AAA.com; data collected on Sept. 7, 2017. National average prices per gallon: regular = \$2.449, premium = \$2.935. The cost differential for premium gasoline on this date is 20%.

⁸ Vehicle fuel economy estimates are available at <https://www.fueleconomy.gov/feg/findacar.shtml>.



The following chart summarizes findings from the static horsepower testing. All tests were a minimum length of 20 seconds from the beginning of the sustained power measurement. Data for each test was truncated to achieve a uniform test duration of 18.5 seconds and then averaged to allow for a quantitative comparison of the results. Graphs of the best runs for each vehicle, using both regular and premium gasoline, are included in the Appendix §13.7.

8.2.2 Static Horsepower Test Results

Vehicle	2000 RPM				4000 RPM			
	Regular HP	Premium HP	Horsepower Gain	Improvement	Regular HP	Premium HP	Horsepower Gain	Improvement
Ford F150	141	143	2	1.1%	272	282	11	3.9%
Cadillac Escalade	131	131	0	0.0%	298	304	6	2.0%
Mazda Miata	41	41	0	0.6%	96	95	-1	-0.9%
Audi A3	69	70	1	1.2%	132	136	4	3.2%
Ford Mustang	100	104	4	4.3%	246	255	9	3.6%
Jeep Renegade	60	60	0	-0.1%	126	126	0	0.2%
Average Results			1.1	1.2%			4.9	2.0%

Figure 16: Results for Static Horsepower Tests

8.2.3 Dynamic Horsepower Measurement

This is your typical “horsepower” test on a chassis dynamometer. Calculations are made based on the tire size, axle ratio, transmission gear ratios, and engine redline to determine the starting and ending wheel speeds. Tire size, axle ratio, transmission gear ratio, starting and ending speeds are entered into the dynamometer software. Tests were typically started between 1500 and 2000 rpm and pushed to redline. The dynamometer software provides wheel/tire power and torque readings.

For example: The Miata had a redline of 7500 rpm, 24.1 inch diameter tires, and a 4.10:1 axle ratio. Calculations resulted in testing the car in 3rd gear (1.33:1), starting the test at 20 mph (~1500 rpm) and ending at 94 mph (~7500 rpm). A higher gear could not be used because the test would exceed the dynamometer limit of 120 mph. Once that data was entered into the dynamometer computer and the test was ready to begin, the driver slowly approached 20 mph in 3rd gear and then floored the accelerator pedal, lifting off only after hitting redline.

8.2.4 Computational Methodology

All runs were averaged using a Bessel Spline interpolation with no extrapolation of data. The averaged data was then graphed and integrated to provide the numerical comparisons for dynamic torque and horsepower produced using premium compared to regular gasoline.



8.2.5 Dynamic Horsepower Test Results

Test vehicles averaged 1.1% improvement in torque and 1.2% improvement in horsepower in dynamic testing.

Vehicle	Dynamic Torque & Horsepower Improvement using Premium	
	Torque	Horsepower
Ford F150	0.8%	1.3%
Cadillac Escalade	0.2%	0.2%
Mazda Miata	2.9%	2.8%
Audi A3	2.0%	2.1%
Ford Mustang	1.8%	1.6%
Jeep Renegade	-1.0%	-1.1%
Average Results	1.1%	1.2%

Figure 17: Summary of Dynamic Torque and Horsepower Using Premium

The following charts show torque and horsepower produced by each of the test vehicles on regular and premium gasoline. Observations about each vehicle's performance follow the charts (8.2.4.1 – 8.2.4.6). Additional charts for each vehicle are located in the Appendix §13.6.



8.2.5.1 2017 Ford F150

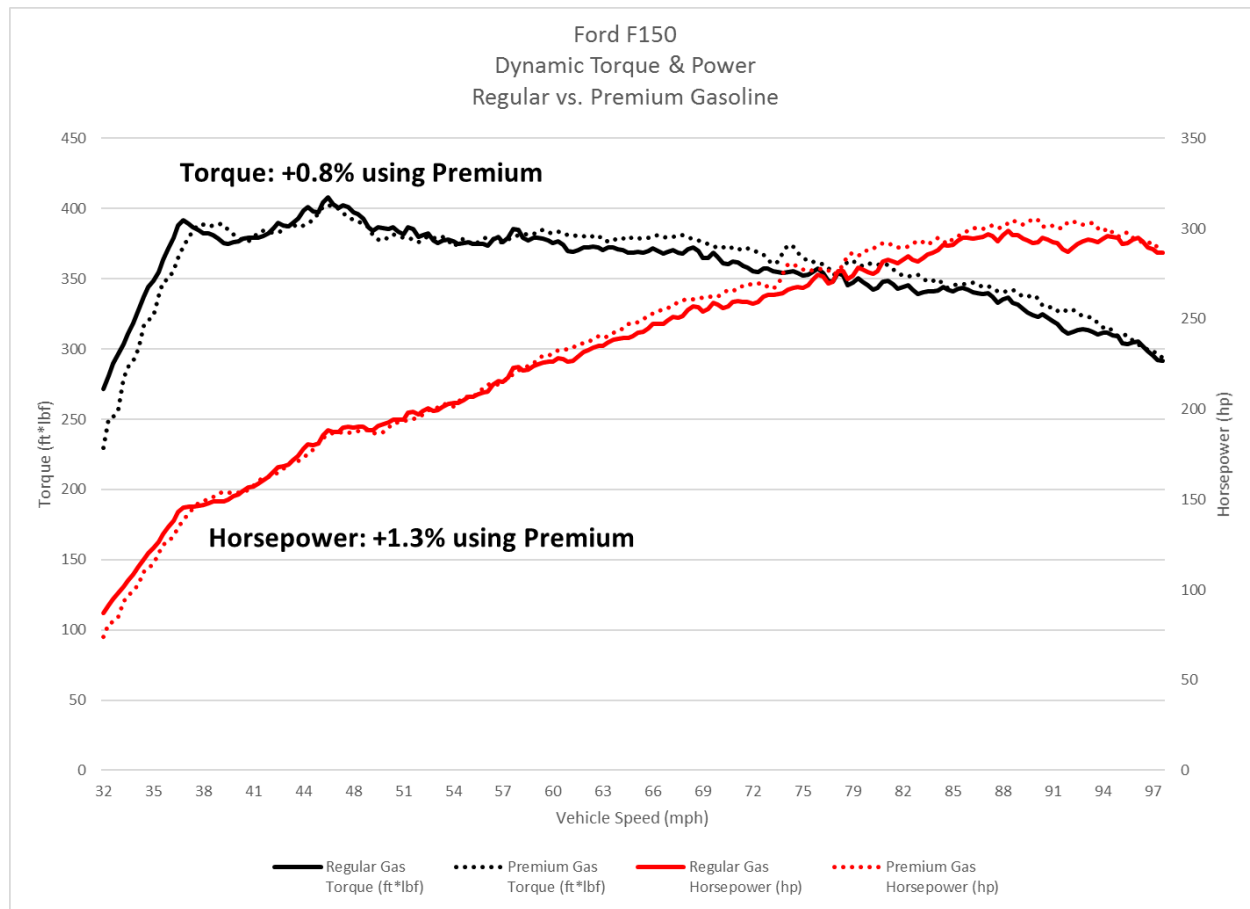


Figure 18: Ford F150 Dynamic Torque and Horsepower

The power and torque output is similar between both fuels at the lower engine speeds, but the premium gasoline shows increases in the mid to high speeds.



8.2.5.2 2016 Cadillac Escalade ESV

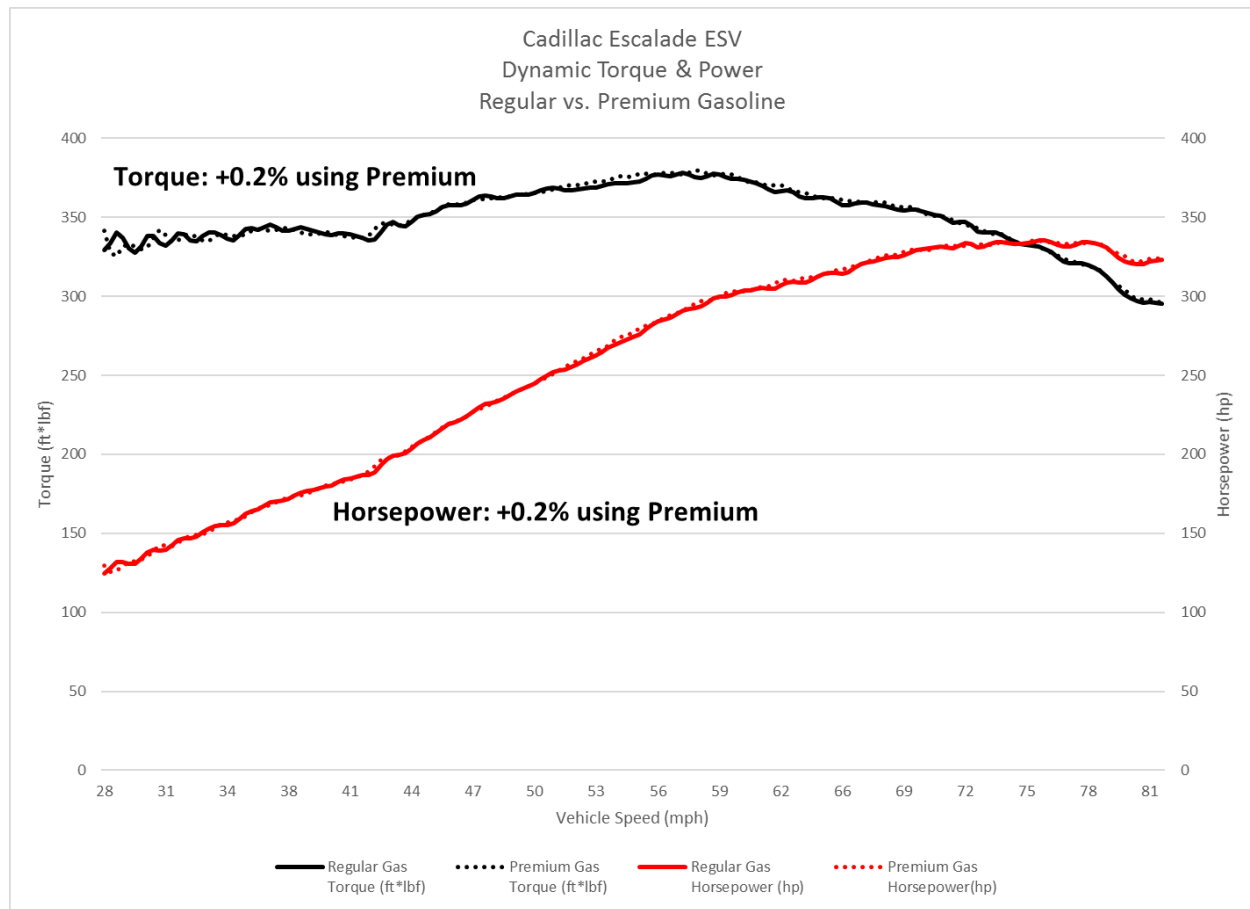


Figure 19: Cadillac Escalade Dynamic Torque and Horsepower

Power and torque measurements were essentially the same for the Escalade on both fuels during the dynamic horsepower tests.



8.2.5.3 2015 Mazda Miata

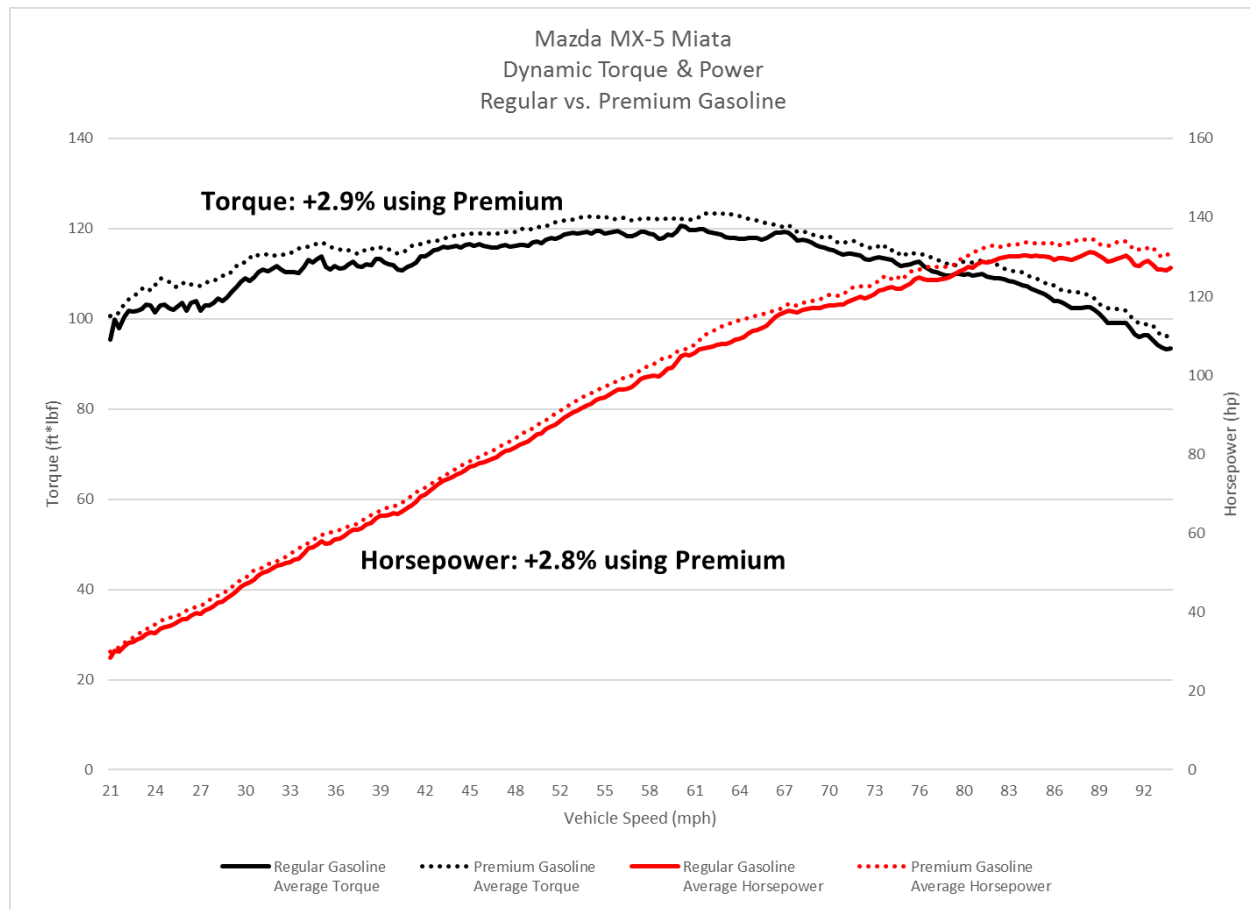


Figure 20: Mazda Miata Dynamic Torque and Horsepower

The chart above shows that the Miata experienced small torque and horsepower gains while running on premium gasoline.



8.2.5.4 2016 Audi A3

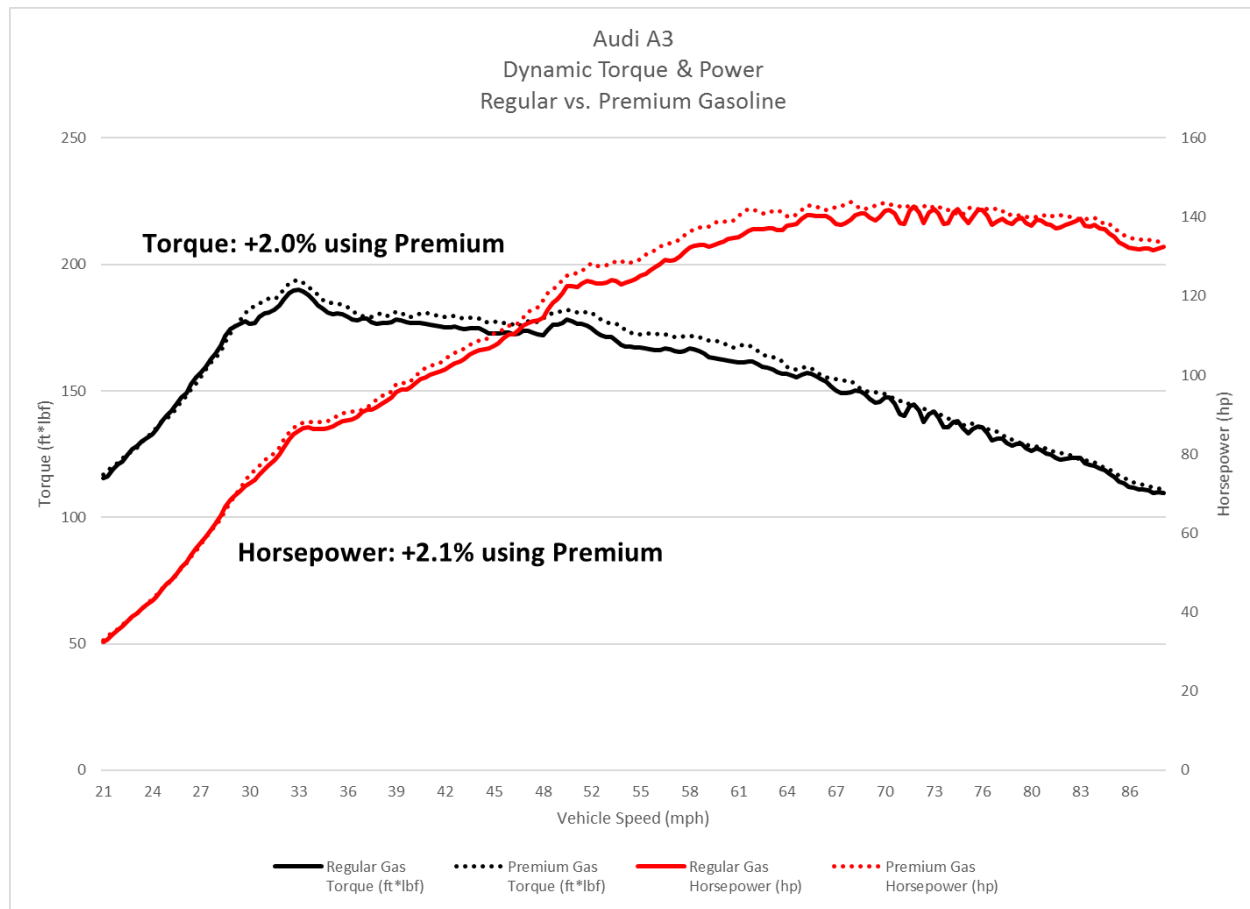


Figure 21: Audi A3 Dynamic Torque and Horsepower

Between speeds near 30 mph and 65 mph, there were small gains in torque and horsepower while running on premium gasoline. The data points are much smoother indicating more consistency at higher octane.

During road testing, the Audi A3 had harsh audible engine knock in road driving using regular gasoline. In real-world driving, this audible knock is the primary decision making factor to select premium gasoline for this vehicle.



8.2.5.5 2017 Ford Mustang GT

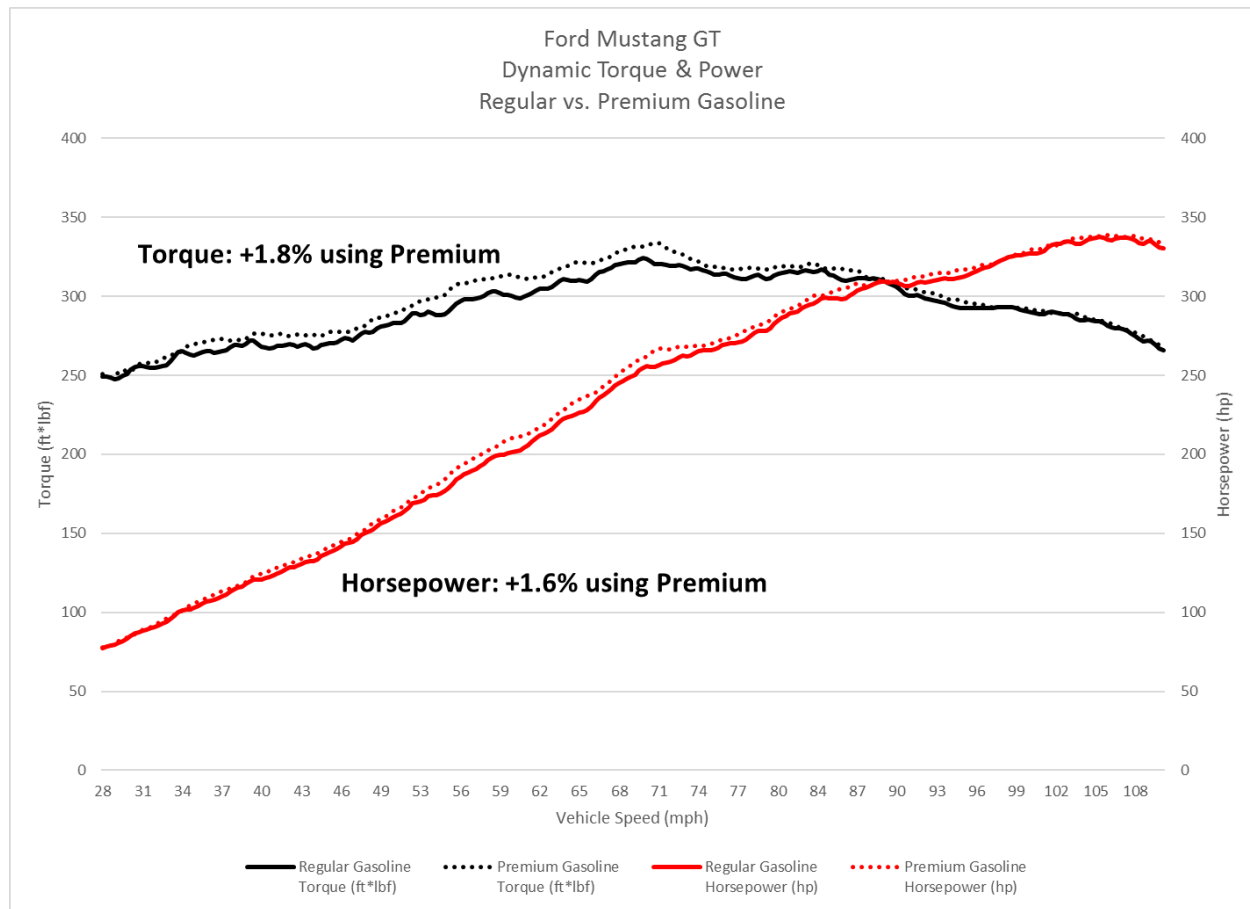


Figure 22: Ford Mustang GT Dynamic Torque and Horsepower

At the low end and higher end of the speeds tested, the horsepower and torque numbers were essentially the same for both fuels. However, the premium gasoline produced a marginal increase in the midrange.



8.2.5.6 2016 Jeep Renegade

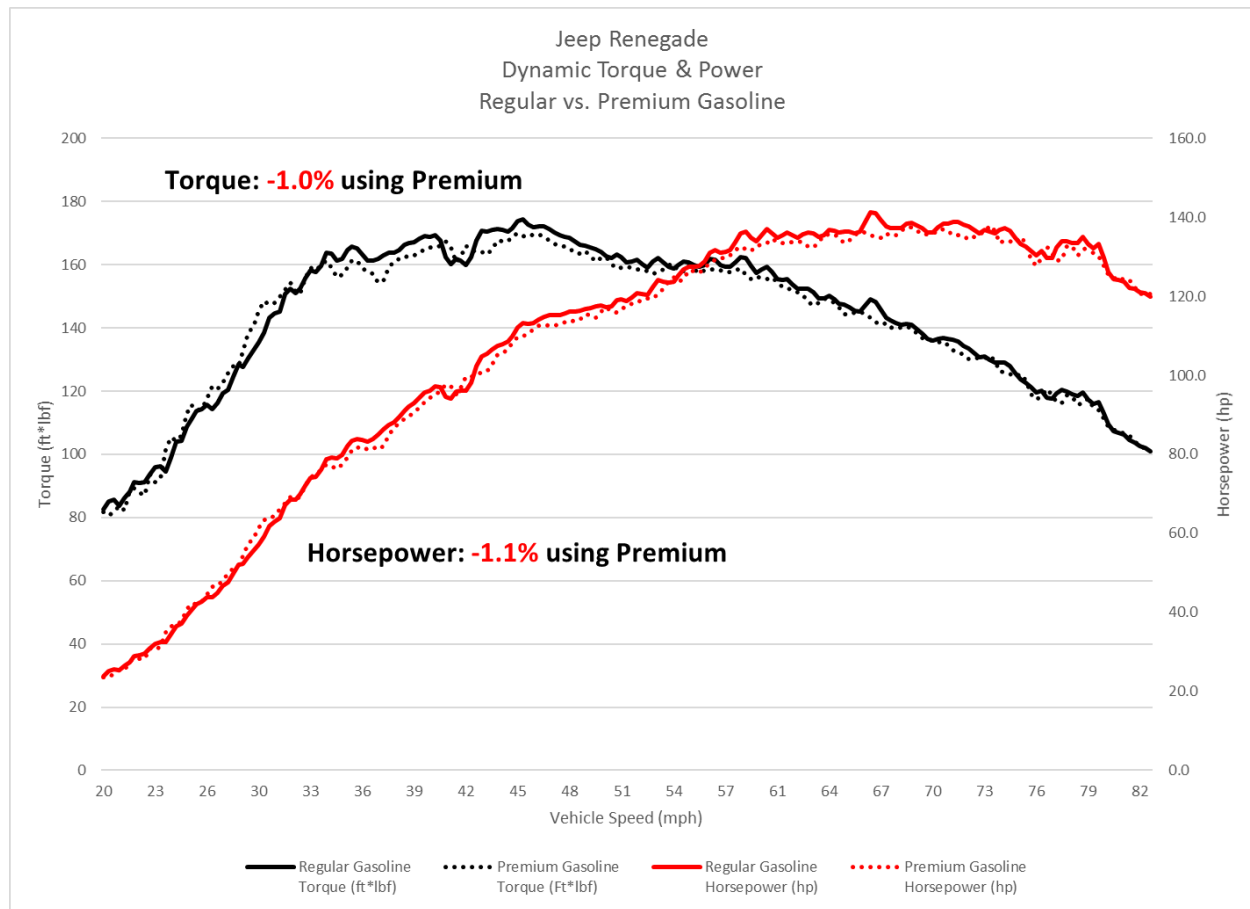


Figure 23: Jeep Renegade Dynamic Torque and Horsepower

While similar results were obtained for the Jeep Renegade on both fuels, the premium gasoline produced slightly less power and torque than regular gasoline.



9 Inquiry #3: What is the difference in retail cost between premium and regular gasoline?

9.1 Objective

Determine if consumers are paying an increasing amount for premium gasoline compared to regular.

9.2 Methodology

AAA researchers reviewed historical, national average pricing data for gasoline in regular and premium grades.

9.3 Price differential findings

From 2002 until 2014, consumers enjoyed a 10% or less cost differential for premium gasoline. Since that time, the extra cost of premium has grown to 20-25%, peaking at just over 30% in 2016. Since 2009, the price differential that consumers pay for premium gasoline has been steadily increasing, rising to 50 cents per gallon in 2016 and remaining near that level.⁹

Since 2014, more vehicles are being manufactured that either recommend or require premium gasoline. Several factors influence this extra cost for premium gasoline, including the drive for more fuel-efficient engines, increased blending of ethanol, and the lack of growth of the supplier base that produces octane increasing fuel additives¹⁰.

For vehicles that recommend, but do not require premium fuel, premium gasoline rarely provides a positive return on the simple dollar investment. However, if over the long term, the vehicle is constantly put under a heavy load, and/or if the vehicle pings or knocks with regular gas, the additional cost to use premium gasoline may save wear and tear on internal engine components, and therefore may have a long-term value.

10 Key Findings

Key Findings:

1. Most vehicles tested showed a modest improvement in fuel economy.

AAA test vehicles averaged 2.7% improvement in fuel economy during testing (not directly comparable to an EPA estimate for MPG). Individual vehicle test result averages ranged from a decrease of 1.0% to an improvement of 7.1%

⁹ Source: AAA

¹⁰ See [Growing octane needs widen the price difference between premium and regular gasoline](https://www.eia.gov/todayinenergy/detail.php?id=31732), U.S. Energy Information Administration. <https://www.eia.gov/todayinenergy/detail.php?id=31732>



Vehicle	Average MPG Improvement* using Premium
Ford F150	5.0%
Cadillac Escalade	7.1%
Mazda Miata	0.7%
Audi A3	-1.0%
Ford Mustang	2.3%
Jeep Renegade	1.9%
Average Results	2.7%

** Average fuel economy improvement is limited to test conditions and not directly comparable to real world driving.*

Figure 24: Average MPG Improvement Using Premium

2. Most vehicles tested showed a modest improvement in performance.

AAA test vehicles averaged an increase in horsepower of 1.4% across all horsepower tests. Individual vehicle test result averages ranged from a decrease of 0.3% to an improvement of 3.2%.

Vehicle	Average Horsepower* Improvement using Premium
Ford F150	2.1%
Cadillac Escalade	0.7%
Mazda Miata	0.8%
Audi A3	2.1%
Ford Mustang	3.2%
Jeep Renegade	-0.3%
Average Results	1.4%

**Horsepower improvement shown is average of AAA tests.*

Figure 25: Average Horsepower Results Using Premium

3. Using national averages, the difference in retail cost between regular and premium gasoline is approximately 20% to 25%, or 50 cents per gallon.



Following more than ten years with a seemingly inelastic price differential of 10% for premium gasoline, the cost of premium has risen steadily since 2010. The price differential for premium peaked near 30% in 2016 and has since remained in the 20% to 25% range.

The fuel economy improvements recorded during AAA testing do not offset the potential extra cost to purchase premium gasoline.

10.1 Statement on the Value of Performance

AAA researchers quantified “performance” in two ways:

1. **Measuring vehicle fuel economy**¹¹ for each vehicle using regular and premium gasolines and comparing the resulting mpg figures
2. **Measuring horsepower** produced by each vehicle using regular and premium gasolines and comparing the resulting horsepower figures

Does an increase in miles per gallon yield a direct savings in fuel costs? No. Opting for premium gasoline in a vehicle labeled premium recommended is unlikely to generate this type of benefit because of the price difference between the two. However, some of the vehicles tested did produce additional torque and horsepower when using premium gasoline. Individual drivers, particularly if their driving style can be described as “spirited,” may find an improvement in vehicle driving performance – off the line acceleration, highway passing, hill-climbing when loaded or towing – and may determine that their personal driving benefits from the use of premium gasoline. For some, the value of performance improvements outweighs the cost savings of using regular gasoline.

11 Summary Recommendations

The following recommendations are specific to vehicles labeled premium recommended. There is not a clear case where premium gasoline is beneficial from a cost perspective. In most cases, the extra cost of premium over regular does not result in a positive return on investment (lower cost to drive a given distance). However, there are instances – and they vary widely by vehicle type and model – where the use of premium gasoline can be marginally beneficial. When shopping for a new vehicle, consider the cost implications of the recommended or required fuel in addition to your expected typical use cases of that vehicle.

Does your vehicle have cylinder deactivation? (i.e., a V-8 engine than can run on only 4 cylinders) If so, you may benefit from premium in “normal” driving as your vehicle is operating

¹¹ Tests performed created increasing engine load for comparison of fuel consumption during the test on regular and premium gasoline. The testing sequence is not the same as used to create EPA estimates for mpg as found on a new vehicle label.



some of the time as a "heavily loaded 4-cylinder". Note the 0% grade results for the Escalade.¹² Try comparable trips using regular and premium gasoline, checking your vehicle's fuel economy, and taking note of vehicle performance.

Every driving trip is a unique combination of driving style, vehicle characteristics, and environmental considerations. Work through the following three questions to see if your situation merits trying premium.

¹² Refer to section 7.3, figure 11.



Should I use Premium Fuel in my "Premium Recommended" vehicle?

There are a few questions to work through in determining if using premium is right for you, your vehicle, and how/where you drive. Answer all three questions ... if you get all "Regular" answers, don't spend the extra money for Premium gasoline. A single recommendation for Premium means you have reason to experiment.

1. Using regular octane fuel, do you have audible knocking (marbles in a coffee can) when accelerating or under heavy load?

Yes	Increase the octane of your gasoline (Regular → Mid-Grade → Premium) until the knocking sound goes away. (If your vehicle still knocks on Premium, see your local AAA Approved Auto Center for diagnosis and repair.)	→	Premium
No	No indication you need to spend the extra money for Premium.	→	Regular

2. Are you driving a heavily loaded truck or SUV, or are you frequently towing?

Yes	MAYBE you'll benefit from using Premium gasoline. There are a lot of variables, and you simply have to make comparable trips using Regular and Premium fuel, checking your vehicle's fuel economy, and taking note of vehicle performance.	→	Premium
No	Probably no reason to spend extra on Premium gasoline ... stick with Regular.	→	Regular

3. Are you driving a "performance" vehicle, and is maximum engine performance important for you?

Yes	You may benefit from Premium in "spirited" driving. The value proposition is highly personal in this case. In a typical "trip", you may only experience the bump in performance (horsepower improvement) for only a few minutes (or seconds) of your drive. If you drive your vehicle hard, you may see a positive difference in fuel economy when using premium - but it's unlikely to average out over a tankful.	→	Premium
No	You are unlikely to experience any noticeable benefit (and will definitely pay more at the pump) when using Premium gasoline. Pocket the savings and choose Regular when filling up.	→	Regular

Answer all three questions. If you get all regular gasoline answers, do not spend the extra money on premium gasoline.



12 References

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- Environmental Protection Agency. (2008). Vehicle labeling of fuel economy, greenhouse gas, and other pollutant emissions information. *49 CFR 575.401*. Federal Register.
- U.S. Environmental Protection Agency. (n.d.). *Detailed Test Information*. Retrieved July 12, 2016, from www.fueleconomy.gov



13 Appendix

13.1 Examples of why premium gasoline is recommended

Recommendation wording
Premium recommended for "severe duty such as trailer tow" for "improved performance."
"For best overall vehicle and engine performance" 91 or higher recommended. Especially hot weather and towing.
Premium recommended for "severe duty such as trailer tow" for "improved performance."
For optimum performance and fuel economy the use of "Premium" 91 octane gasoline or higher is recommended.
Use of unleaded gasoline with an octane rating lower than 91 may result in engine knocking and significantly reduced performance.
For vehicles with (<i>specific to one manufacturer</i>) engines, to provide improved performance, we recommend premium fuel for severe duty usage such as trailer tow.
For (<i>specific to one manufacturer</i>) engines, premium recommended for "severe duty such as trailer tow" for "improved performance."
An octane rating lower than 91 may result in engine knocking and significantly reduced performance.
To provide improved performance, we recommend premium fuel for severe duty usage, such as trailer tow.
Premium Fuel will provide improved performance and is recommended for severe duty usage such as trailer tow.
For optimum performance and fuel economy the use of 91 octane or higher is recommended.
For optimum performance and fuel economy the use of 91 octane or higher is recommended.
Regular unleaded gasoline rated at 87 octane or higher can be used, but acceleration and fuel economy will be reduced.
87 may be used ... "you may notice a decrease in performance."
87 octane or higher can be used, but acceleration and fuel economy will be reduced.
(<i>This manufacturer</i>) recommends premium fuel for best performance, but using 87 octane or above will not affect engine reliability.
If 87 is used, "acceleration and fuel economy will be reduced, and an audible knocking noise may be heard."
... may notice a slight decrease in maximum engine performance while using 91 fuel ... 87 or higher may also be used.
To provide improved performance we recommend premium fuel for severe duty usage such as trailer tow.
87 to 90 (91 to 95 RON) can be used, but this will reduce performance slightly.

Figure 26: Examples of explanation for premium recommended



13.2 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.
- Knock
 - The mixture of air and fuel in the engine cylinder is intended to be ignited by the spark plug only. Knock occurs when part of the air-fuel charge self-ignites before the flame arrives, due to high cylinder pressure and temperature. The sudden pressure increase 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 knock. 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 knock.
- Horsepower
 - Torque is the “twisting force” that moves the car from a stop. Exhilarating acceleration from a stand-still 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. ($\text{torque} * \text{rpm} / 5,252 = \text{horsepower}$)
- Tailpipe emissions and how they are quantified
 - Total hydrocarbons (THC), measured in parts per million Carbon (ppmC), hydrocarbons in the exhaust are primarily unburned gasoline
 - Methane (CH₄), measured in parts-per-million (ppm), methane 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 higher concentrations and can lead to fatal air poisoning
- Carbon dioxide (CO₂), measured as a percentage of gaseous tailpipe emissions, is a greenhouse gas. The increasing concentration of CO₂ 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. (Environmental Protection Agency, 2008) 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. (U.S. Environmental Protection Agency, n.d.)



13.3 Vehicles labeled premium recommended

Sub-compact	Group 4	Ford	2016 Ford	Fiesta	fordservic	116	Ecoboost	1.0 L Turb	yes	Direct	87	"Premium"	yes
Large/Crossover	Group 4	Ford	2016 Ford	Taurus	fordservic	142	Ecoboost	2.0 L Turb	yes	Direct	87		91 yes
Compact SUV	Group 4	Ford	2016 Ford	Flex	fordservic	154	Ecoboost	3.5 L Turb	yes	Direct	87	NA	yes
Sub-compact	Group 4	Fiat-Chrysler	2016 Fiat	500	dealerrepr	296		1.4 L Turb	yes	Direct	87		91 yes
Mid-size	Group 4	Toyota	2016 Lexus	GS 200t	lexus.com	555	200T	2.0 L Turb	yes	Direct	87		91 yes
Large/Crossover	Group 4	Ford	2016 Ford	Taurus	fordservic	142	Ecoboost	3.5 L Turb	yes	Direct	87		91 yes
Other	Group 4	Ford	2016 Ford	Transit Co	fordservic	119		1.6 L Turb	yes	Direct	87	"Premium"	yes
Compact	Group 4	Ford	2016 Ford	Focus	fordservic	130	Ecoboost	1.0 L Turb	yes	Direct	87		91 yes
Sub-compact	Group 4	Ford	2016 Ford	Fiesta	fordservic	116	Ecoboost	1.6 L Turb	yes	Direct	87	"Premium"	yes
Large/Crossover	Group 4	Ford	2016 Ford	Edge	fordservic	159	Ecoboost	2.7 L Turb	yes	Direct	87	"Premium"	yes
Sports Car	Group 4	Ford	2016 Ford	Mustang	fordservic	125	Ecoboost	2.3 L Turb	yes	Direct	87	"Premium"	yes
Compact SUV	Group 4	Toyota	2016 Lexus	NX 200t	lexus.com	599		2.0 L Turb	yes	Direct	87		91 yes
Large/Crossover	Group 4	Ford	2016 Ford	Edge	fordservic	159	Ecoboost	2.0 L Turb	yes	Direct	87	"Premium"	yes
Mid-size	Group 4	Ford	2016 Ford	Fusion	fordservic	155	Ecoboost	1.5 L Turb	yes	Direct	87	"Premium"	yes
Mid-size	Group 4	Ford	2016 Ford	Fusion	fordservic	155	Ecoboost	2.0 L Turb	yes	Direct	87	"Premium"	yes
Truck	Group 4	Ford	2016 Ford	F-150	"Octane-reqs-list"			2.7 L Turb	yes	Direct	87	"Premium"	yes
Truck	Group 4	Ford	2016 Ford	F-150	"Octane-reqs-list"			3.5 L Turb	yes	Direct	87	"Premium"	yes
Compact SUV	Group 4	Ford	2016 Ford	Escape	fordservic	130	Ecoboost	2.0 L Turb	yes	Direct	87	NA	yes
Compact	Group 4	Ford	2016 Ford	Focus ST	fordservic	130	Ecoboost	2.0 L Turb	yes	Direct	87		91 yes
Compact SUV	Group 4	Ford	2016 Ford	Escape	fordservic	130	Ecoboost	1.6 L Turb	yes	Direct	87	NA	yes
Compact	Group 4	Ford	2014 Ford	Fiesta	"Octane-reqs-list"			1.0 L Turb	yes	Direct	87	"Premium"	yes
Compact	Group 4	Fiat-Chrysler	2016 Dodge	Dart	"Octane-reqs-list"			1.4 L Turb	yes	Direct	87		91 yes
Large/Crossover	Group 4	Fiat-Chrysler	2016 Jeep	Renegade	jeep.com	388		1.4 L Turb	yes	Direct	87		91 yes
Sub-compact	Group 4	Fiat-Chrysler	2017 Fiat	500L	"Octane-reqs-list"			1.4 L Turb	yes	Direct	87		91 yes
Sub-compact	Group 4	Fiat-Chrysler	2017 Fiat	500X	"Octane-reqs-list"			1.4 L Turb	yes	Direct	87		91 yes
Large/Crossover	Group 4	Fiat-Chrysler	2017 Jeep	Renegade	"Octane-reqs-list"			1.4 L Turb	yes	Direct	87		91 yes
Mid-size	Group 4	GM	2016 Buick	Cascada	buick.com	248		1.6 L Turb	yes	Direct	87		91 yes
Compact	Group 4	Ford	2014 Ford	Fiesta	"Octane-reqs-list"			1.6 L Turb	yes	Direct	87	"Premium"	yes
Compact SUV	Group 4	Renault	2016 Nissan	Juke	nissanusa.	370		1.6 L Turb	yes	Direct	87		91 yes
Compact	Group 4	GM	2016 Cadillac	ATS	cadillac.cc	279		2.0 L	yes	Direct	87		91 yes
Mid-size	Group 4		2016 Volvo	S80	volvocars.	262	T11	2.0 L Turb	yes	Direct	87	"Premium"	yes
Mid-size	Group 4		2016 Volvo	V60	volvocars.	380	T11	2.0 L Turb	yes	Direct	87	"Premium"	yes
Large/Crossover	Group 4		2016 Volvo	XC60	volvocars.	277	T11	2.0 L Turb	yes	Direct	87	"Premium"	yes
Large/Crossover	Group 4		2016 Volvo	XC70	volvocars.	276	T11	2.0 L Turb	yes	Direct	87	"Premium"	yes
Compact	Group 4		2016 Volvo	S60	volvocars.	274	T11,T12	2.0 L Turb	yes	Direct	87	"Premium"	yes
Sports Car	Group 4	GM	2016 Chevy	Camaro	chevrolet.	242		2.0 L Turb	yes	Direct	87		91 yes
Large/Crossover	Group 4	GM	2016 Cadillac	CT6	cadillac.cc	254		2.0 L Turb	yes	Direct	87		91 yes
Mid-size	Group 4	GM	2016 Cadillac	CTS	cadillac.cc	251		2.0 L Turb	yes	Direct	87		91 yes
Compact SUV	Group 4	Subaru	2016 Subaru	Forester	subaru.co	3		2.0 L Turb	yes	Direct	87	91 (93)	yes
Mid-size	Group 4	GM	2016 Chevy	Malibu	chevrolet.	269		2.0 L Turb	yes	Direct	87		91 yes
Large/Crossover	Group 4	Ford	2016 Lincoln	MKC	fordservice	164		2.0 L Turb	yes	Direct	87	"Premium"	yes
Mid-size	Group 4	Ford	2016 Lincoln	MKZ	fordservice	167		2.0 L Turb	yes	Direct	87	"Premium"	yes
Sports Car	Group 4	Ford	2016 Mazda	MX-5	mazdausa	76		2.0 L Turb	yes	Direct	87		91 yes
Mid-size	Group 4	GM	2016 Buick	Regal	buick.com	214		2.0 L Turb	yes	Direct	87		91 yes
Compact	Group 4	GM	2016 Buick	Verano	buick.com	217		2.0 L Turb	yes	Direct	87		91 yes
Compact	Group 4	Subaru	2016 Subaru	WRX	subaru.co	3		2.0 L Turb	yes	Direct	87		91 yes
Sports Car	Group 4	Ford	2015 Ford	Mustang	"Octane-reqs-list"		Ecoboost	2.3 L Turb	yes	Direct	87	"Premium"	yes
Large/Crossover	Group 4	Ford	2016 Lincoln	MKC	fordservice	164		2.3 L Turb	yes	Direct	87	"Premium"	yes
Compact	Group 4		2016 Volvo	S60	volvocars.	274		2.5 L Turb	yes	Direct	87	"Premium"	yes
Mid-size	Group 4		2016 Volvo	V60	volvocars.	380		2.5 L Turb	yes	Direct	87	"Premium"	yes
Large/Crossover	Group 4		2016 Volvo	XC60	volvocars.	277		2.5 L Turb	yes	Direct	87	"Premium"	yes
Large/Crossover	Group 4		2016 Volvo	XC70	volvocars.	276		2.5 L Turb	yes	Direct	87	"Premium"	yes
Compact	Group 4		2016 Volvo	S60	volvocars.	274		3.0 L Turb	yes	Direct	87	"Premium"	yes
Mid-size	Group 4		2016 Volvo	V60	volvocars.	380		3.0 L Turb	yes	Direct	87	"Premium"	yes
Large/Crossover	Group 4		2016 Volvo	XC60	volvocars.	277		3.0 L Turb	yes	Direct	87	"Premium"	yes
Compact SUV	Group 4	Ford	2016 Lincoln	MKT	fordservice	168	Ecoboost	3.5 L Turb	yes	Direct	87	"Premium"	yes
SUV	Group 4	Ford	2016 Lincoln	Navigator	fordservice	159		3.5 L Turb	yes	Direct	87	"Premium"	yes

Figure 27: List of Vehicles labeled premium recommended



13.4 Test Fuel Analysis Reports

13.4.1 Regular

haltermannsolutions[®]

Telephone: (800) 969-2542

Product Information

FAX: (281) 457-1469

PRODUCT: **EPA Tier 3 EEE**
Emission Certification Fuel
General Testing - Regular
HF2021

Batch No.: FA0921BE10

Tank No.: Drums

TEST	METHOD	UNITS	SPECIFICATIONS			RESULTS
			MIN	TARGET	MAX	
Distillation - IBP	ASTM D86 ¹	°F				94.7
5%		°F				119.6
10%		°F	120		140	128.8
20%		°F				139.9
30%		°F				148.1
40%		°F				154.4
50%		°F	190		210	200.1
60%		°F				230.8
70%		°F				253.4
80%		°F				279.2
90%		°F	315		335	318.0
95%		°F				339.4
Distillation - EP		°F	380		420	389.1
Recovery		ml		Report		97.5
Residue		ml			2.0	1.0
Loss		ml		Report		1.5
Gravity @ 60° F	ASTM D4052 ¹	°API		Report		58.19
Density @ 15.56° C	ASTM D4052 ¹	kg/l		Report		0.7452
Reid Vapor Pressure EPA Equation	ASTM D5191 ¹	psi	8.7		9.2	9.1
Carbon	ASTM D5291 ²	wt fraction		Report		0.8263
Hydrogen	ASTM D5291 ²	wt fraction		Report		0.1366
Hydrogen/Carbon ratio	ASTM D5291 ²	mole/mole		Report		1.970
Oxygen	ASTM D4815 ²	wt %		Report		3.66
Ethanol content	ASTM D5599-00	vol %	9.6		10.0	9.8
Total oxygenates other than ethanol	ASTM D4815 ²	vol %			0.1	None Detected
Sulfur	ASTM D5453 ²	mg/kg	8.0		11.0	9.0
Phosphorus	ASTM D3231 ²	g/l			0.0013	None Detected
Lead	ASTM D3237 ²	g/l			0.0026	None Detected
Composition, aromatics	ASTM D5769 ²	vol %	21.0		25.0	22.6
C6 aromatics (benzene)	ASTM D5769 ²	vol %	0.5		0.7	0.5
C7 aromatics (toluene)	ASTM D5769 ²	vol %	5.2		6.4	5.9
C8 aromatics	ASTM D5769 ²	vol %	5.2		6.4	5.9
C9 aromatics	ASTM D5769 ²	vol %	5.2		6.4	5.7
C10+ aromatics	ASTM D5769 ²	vol %	4.4		5.6	4.7
Composition, olefins	ASTM D6550	wt %	4.0		10.0	5.2
Oxidation Stability	ASTM D525 ²	minutes	1000			1000+
Copper Corrosion	ASTM D130 ²				1	1a
Existent gum, washed	ASTM D381 ²	mg/100mls			3.0	0.8
Existent gum, unwashed	ASTM D381 ²	mg/100mls		Report		1.2
Research Octane Number	ASTM D2699 ²			Report		91.8
Motor Octane Number	ASTM D2700 ²			Report		84.2
R+M/2	D2699/2700 ²		87.0		88.4	88.0
Sensitivity	D2699/2700 ²		7.5			7.6
Net Heat of Combustion	ASTM D240 ²	BTU/lb		Report		17972

¹ Haltermann Solutions is accredited to ISO/IEC 17025 by A2LA for the tests referred to with this footnote.² Tested by ISO/IEC 17025 accredited subcontractor.

Gasoline and diesel specialty fuels from Haltermann Solutions shall remain within specifications for a minimum of 3 years from the date on the COA so long as the drums are sealed and unopened in their original container and stored in a warehouse at ambient conditions. Specialty fuels that have been intentionally modified for aggressive or corrosive properties are excluded.

Main Lab, 15600 West Hardy, Houston TX 77060

Figure 28: Test Fuel Analysis - Regular



13.4.2 Premium



Product Information

FAX: (281) 457-1469

PRODUCT: EPA Tier 3 EEE
Emission Certification Fuel,
General Testing - Premium
Specification No.: HF2042

Batch No.: EH0521BE10

Tank No.: TRLU024784-7

TEST	METHOD	UNITS	SPECIFICATIONS			RESULTS
			MIN	TARGET	MAX	
Distillation - IBP	ASTM D86	°F				96.6
5%		°F				120.2
10%		°F	120		140	129.8
20%		°F				142.4
30%		°F				150.4
40%		°F				160.1
50%		°F	190		210	205.9
60%		°F				227.8
70%		°F				250.0
80%		°F				281.9
90%		°F	315		335	324.8
95%		°F				342.0
Distillation - EP		°F	380		420	386.9
Recovery		vol %		Report		97.2
Residue		vol %			2.0	1.0
Loss		vol %		Report		1.8
Gravity @ 60° F	ASTM D4052	°API		Report		58.4
Density @ 15.56° C	ASTM D4052	-		Report		0.7444
Reid Vapor Pressure EPA Equation	ASTM D5191	psi	8.7		9.2	9.16
Carbon	ASTM D5291	wt fraction		Report		0.827
Hydrogen	ASTM D5291	wt fraction		Report		0.137
Hydrogen/Carbon ratio	ASTM D5291	mole/mole		Report		1.974
Oxygen	ASTM D4815	wt %		Report		3.64
Ethanol content	ASTM D5599-00	vol%	9.6		10.0	9.8
Total oxygenates other than ethanol	ASTM D4815	vol%			0.1	None Detected
Sulfur	ASTM D5453	mg/kg	8.0		11.0	10.0
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	23.2
C6 aromatics (benzene)	ASTM D5769	vol %	0.5		0.7	0.6
C7 aromatics (toluene)	ASTM D5769	vol %	5.2		6.4	5.8
C8 aromatics	ASTM D5769	vol %	5.2		6.4	6.2
C9 aromatics	ASTM D5769	vol %	5.2		6.4	5.5
C10+ aromatics	ASTM D5769	vol %	4.4		5.6	5.2
Composition, olefins	ASTM D6550	wt%	4.0		10.0	4.7
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		0.5
Research Octane Number	ASTM D2699			Report		97.4
Motor Octane Number	ASTM D2700			Report		87.8
R+M/2	D2699/2700		91.0			92.6
Sensitivity	D2699/2700		7.5			9.6
Net Heat of Combustion	ASTM D240	BTU/lb		Report		17986

Gasoline and diesel specialty fuels from Haltermann Solutions shall remain within original specifications for a minimum of 3 years from the date on the COA so long as the drums are sealed and unopened in their original container and stored in a warehouse at ambient conditions. Specialty fuels that have been intentionally modified for aggressive or corrosive properties are excluded.

Figure 29: Test Fuel Analysis - Premium



13.5 Vehicle Acceptance checklist

At vehicle pick-up location

- Model-year
- Engine
- Mileage
- Gear selector
- Exhaust tips
- Tires – condition, size, matched
- Tow hooks / anchor points
- Damage inspection
- Leak inspection
- Ask when last service / oil change was done
- Fluid levels / condition

On-road

- Drives OK, straight, no pull
- Holds manually selected gear
- No pinging under load

Check-in

- **Pictures**
 - Vehicle exterior – all around
 - Vehicle interior (cockpit from left shoulder of driver position – show dash, gearshift, steering wheel controls, etc.)
 - Labels – Underhood VECI, door jamb tire info
 - Tires
 - Fuel door
 - Exhaust system
- Pressure test exhaust system to find leaks, seal as needed
- Exhaust tips – removal necessary for emissions testing?
- Frame/body/sub frame straight?



- Aftermarket parts?
- Fluid Leaks?
- OBD Scan
- TSBs
- Certification info
- Finalize anchor points
- Set tire pressure

On pump gas

- On-road grade testing
- Secure vehicle on dynamometer
- Warmup – 2x HWFET
- Road-Load Derivation (RLD)
- Verify vehicle holds manually selected gear on dynamometer
- Verify no large exhaust leaks
- Figure out start & end speeds and gear choice for dynamic HP test
- Verify static HP test works – holds gear, what speeds and gear choice
- Verify 4-bag emissions test runs OK, note if gear hunting is present

On test fuel

- Drain fuel
- Fill 10%
- Clear codes (reset fuel trim)
- Short on-road drive to mix and dilute any residual leftover fuel with new fuel
- Drain fuel
- Fill 75%
- Clear codes (reset fuel trim)
- Road drive for fuel system learning
 - Various speeds, loads, grades
 - Listen for knock
 - Log OBD data



- Record OBD Monitor status
- Secure on dynamometer
- Warm up
- 4 bag grade test x3 (0%, 2%, 4% at 65 mph, 6% at 55 mph)* *subject to CVS limitations*
 - Log OBD parameters including engine load
 - if gear hunting is present, lock in the lower of the 2 gears for subsequent tests (3 good)
- Dynamic HP tests until 3 good results, w/ cool down (cats, engine, etc.) in between
- Static HP tests, 2 engine speeds (2000 & 4000 rpm), 3x good each w/ cool down in between
 - Cool down defined as catalyst temp below 500°F and coolant back to nominally regulating temperature
- Review results before moving onto next fuel or releasing vehicle



13.6 Dynamic Torque and Power Results

The following charts show all test runs on both regular and premium gasoline for all test vehicles.

13.6.1 2017 F150

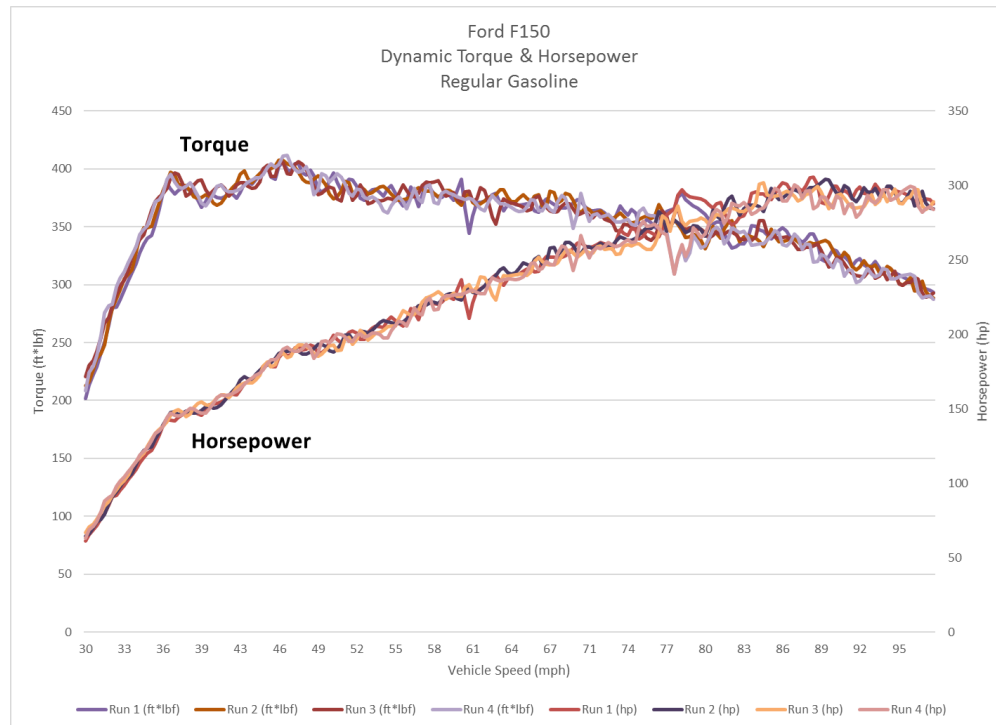


Figure 30: Ford F150 Dynamic Torque & Horsepower - All Runs on Regular Gasoline

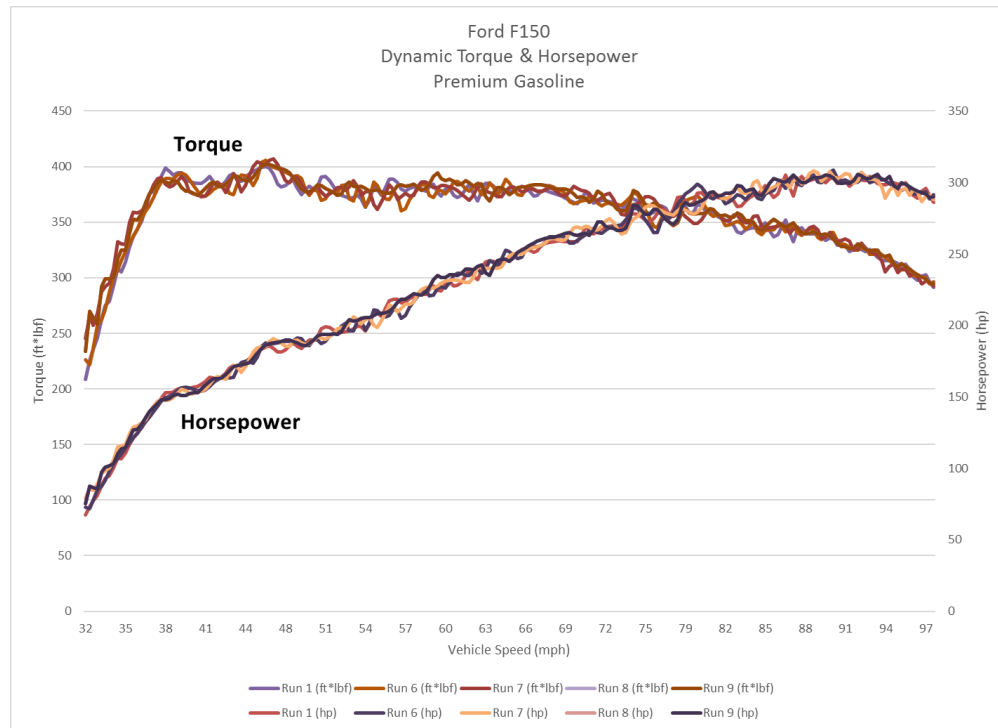


Figure 31: Ford F150 Dynamic Torque & Horsepower - All Runs on Premium Gasoline

13.6.2 2016 Cadillac Escalade ESV

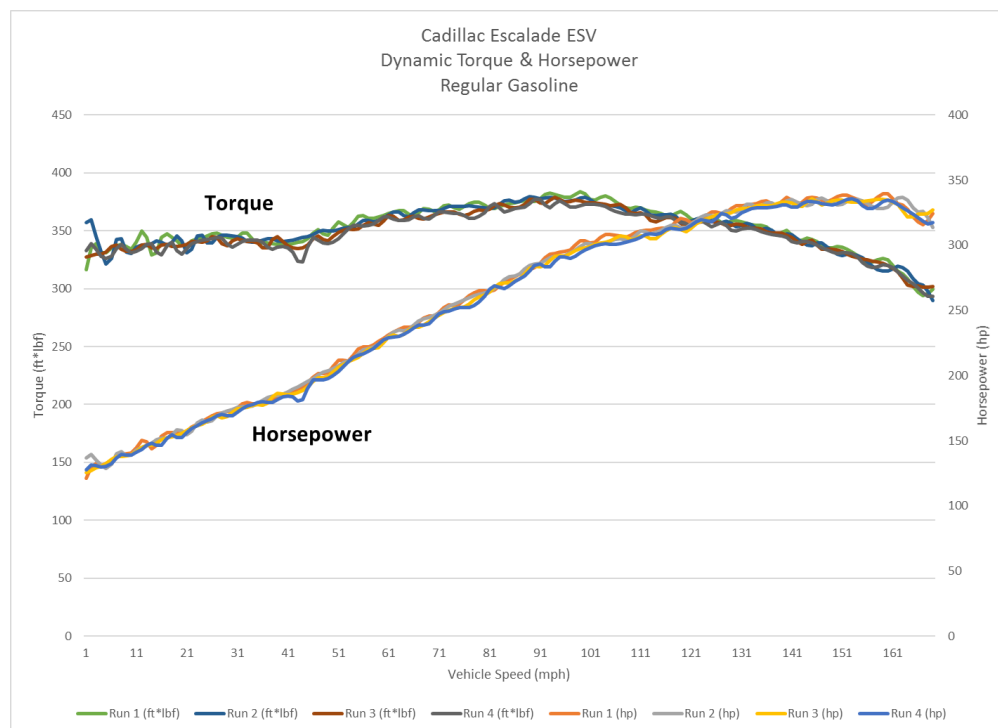


Figure 32: Cadillac Escalade ESV Dynamic Torque & Horsepower - All Runs on Regular Gasoline

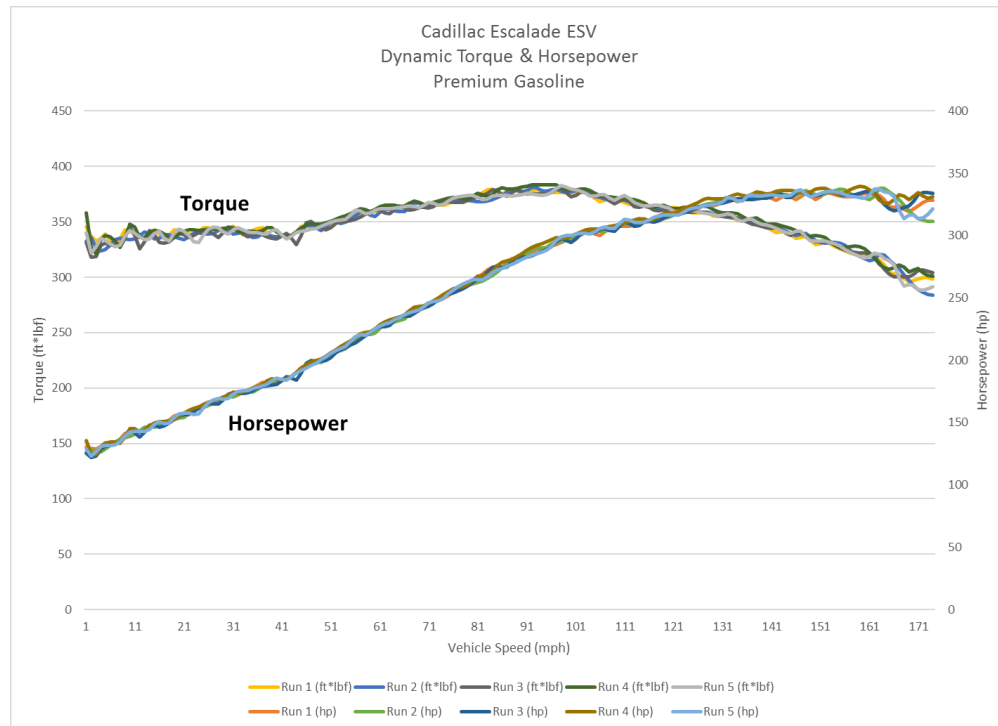


Figure 33: Cadillac Escalade ESV Dynamic Torque & Horsepower - All Runs on Premium Gasoline

13.6.3 2015 Mazda Miata

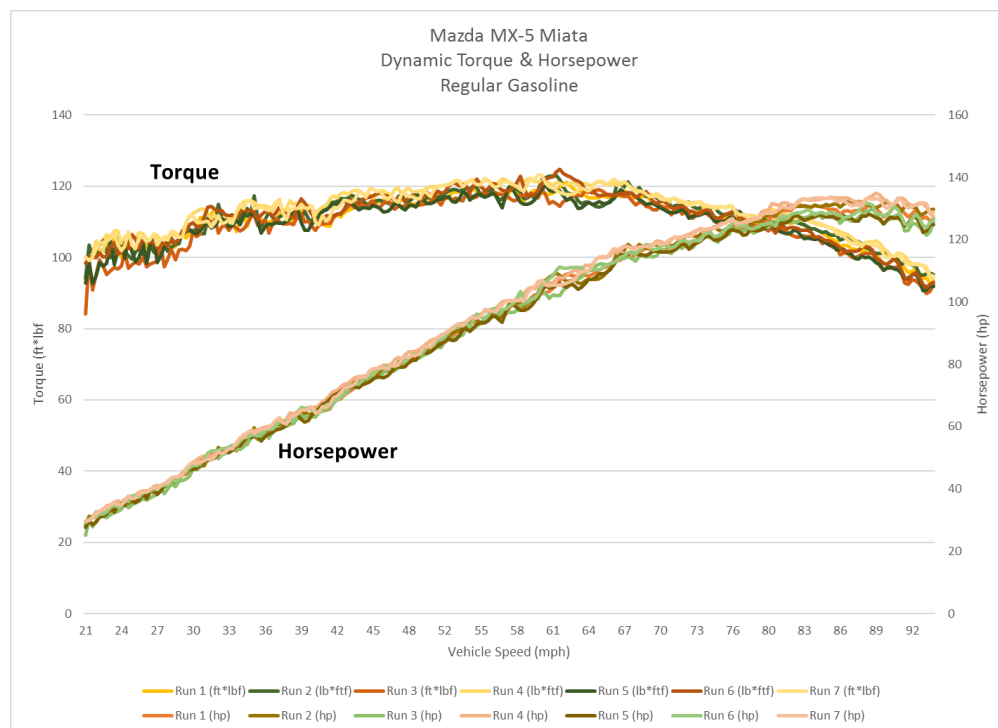


Figure 34: Mazda Miata Dynamic Torque & Horsepower - All Runs on Regular Gasoline

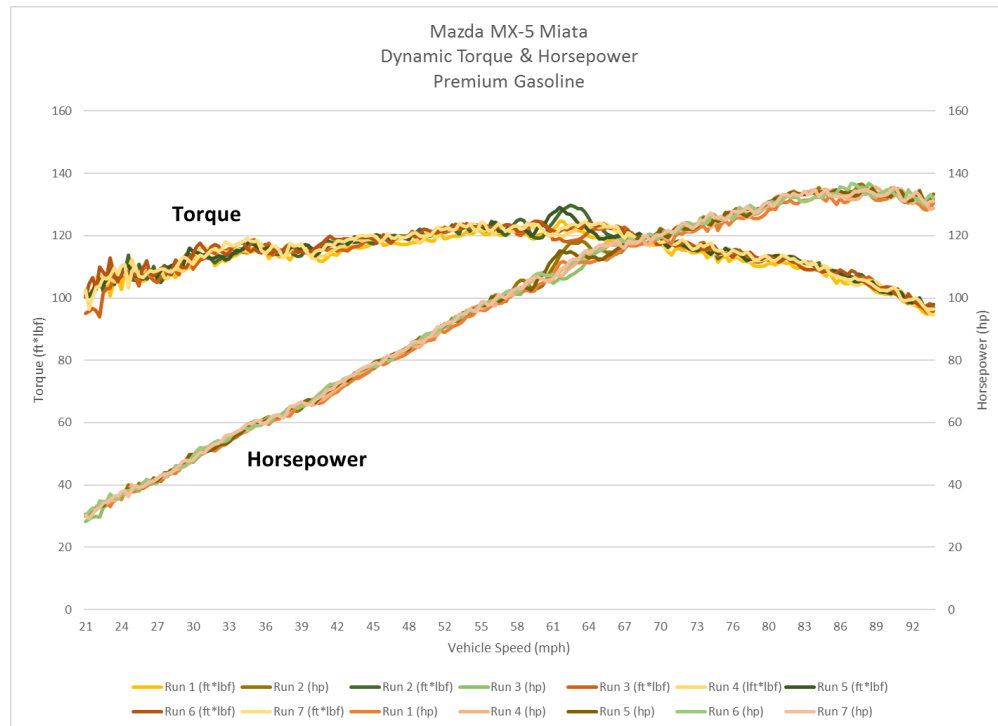


Figure 35: Mazda Miata Dynamic Torque & Horsepower - All Runs on Premium Gasoline



13.6.4 2016 Audi A3

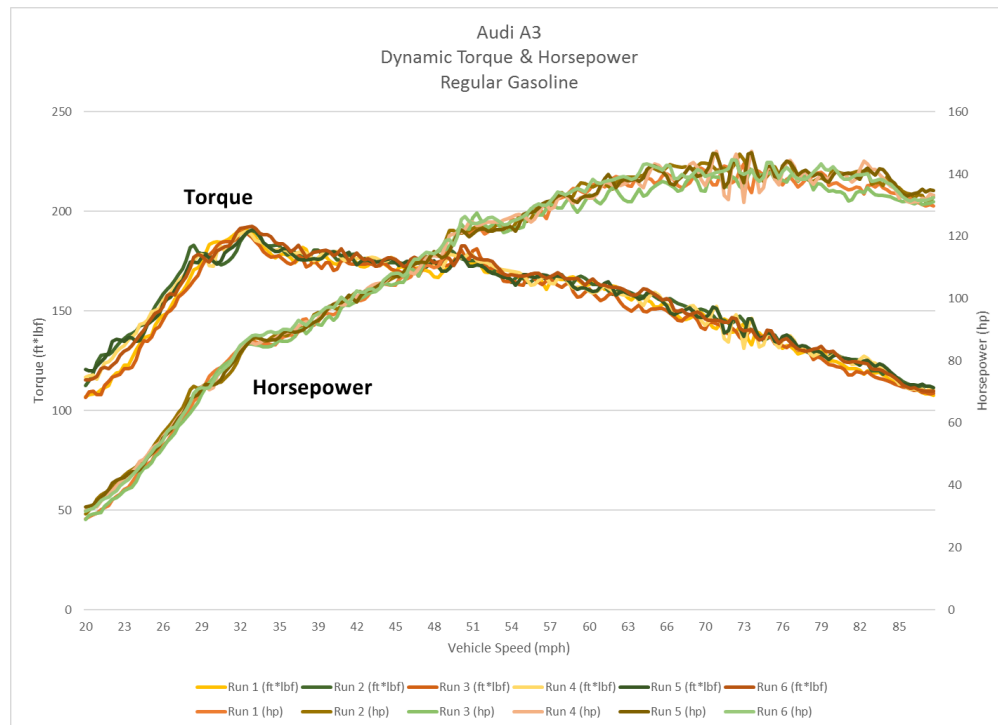


Figure 36: Audi A3 Dynamic Torque & Horsepower - All Runs on Regular Gasoline

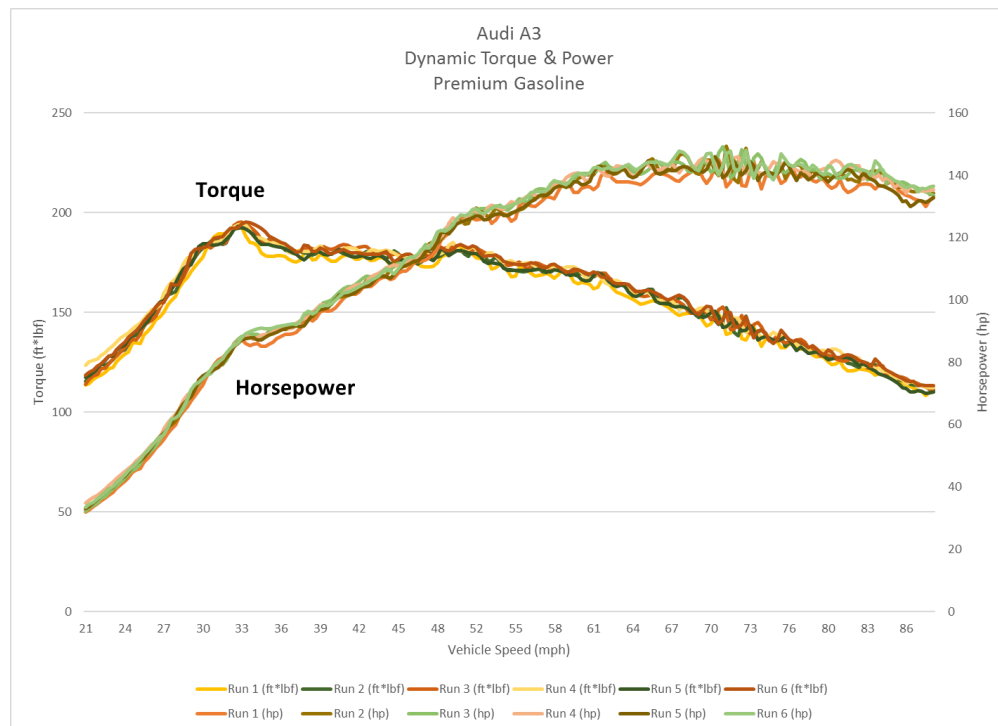


Figure 37: Audi A3 Dynamic Torque & Horsepower - All Runs on Premium Gasoline



13.6.5 2017 Ford Mustang GT

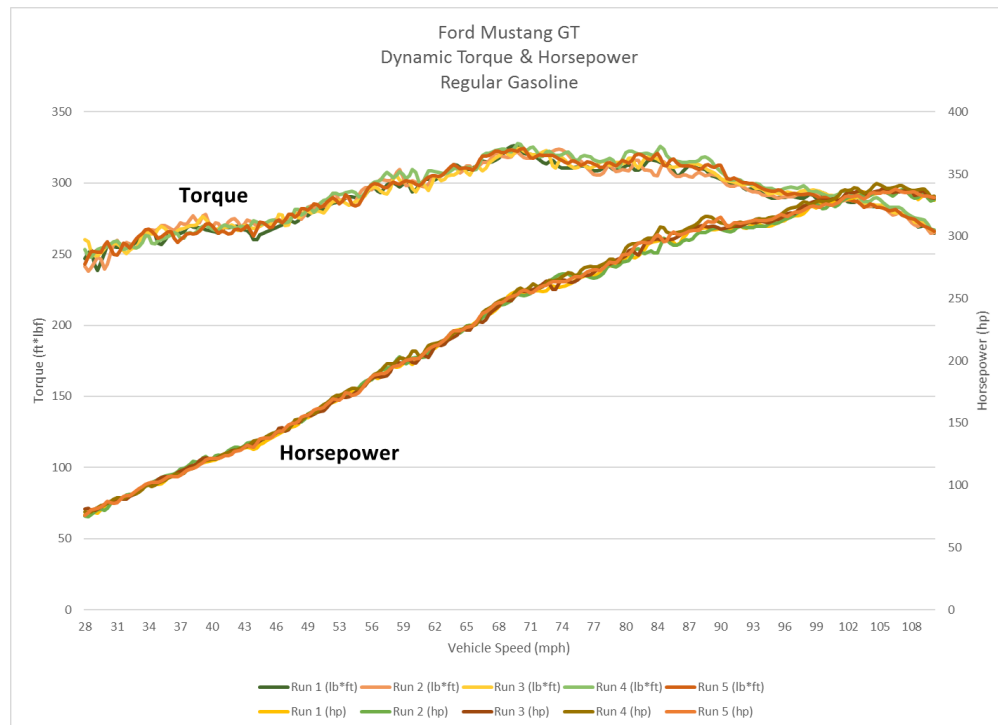


Figure 38: Ford Mustang GT Dynamic Torque & Power - All Runs on Regular Gasoline

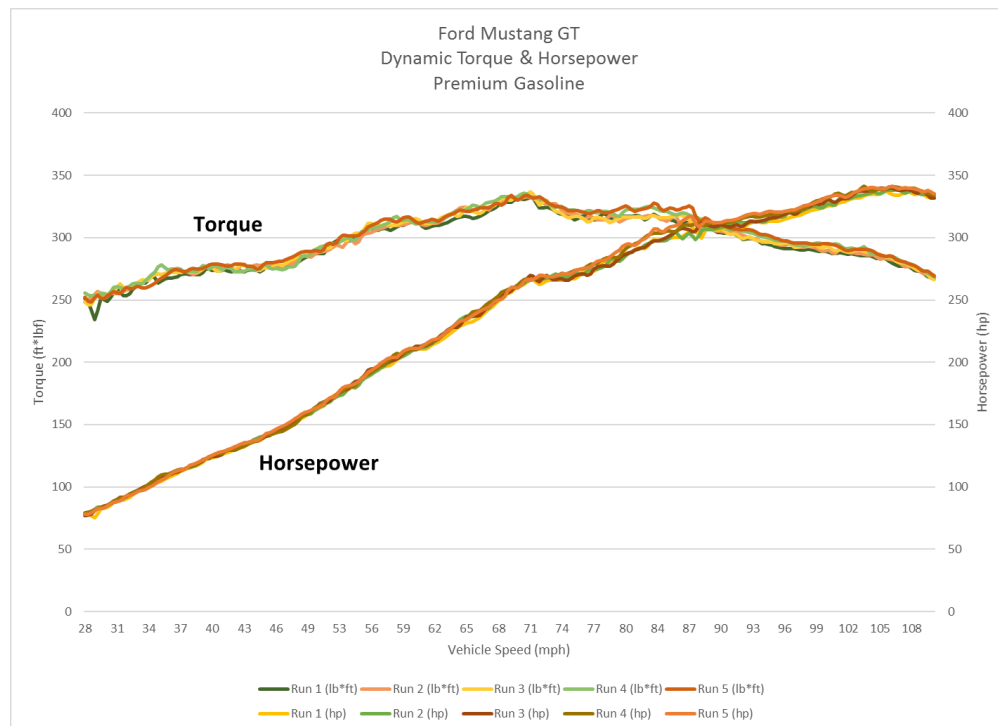


Figure 39: Ford Mustang GT Dynamic Torque & Power - All Runs on Premium Gasoline



13.6.6 2016 Jeep Renegade

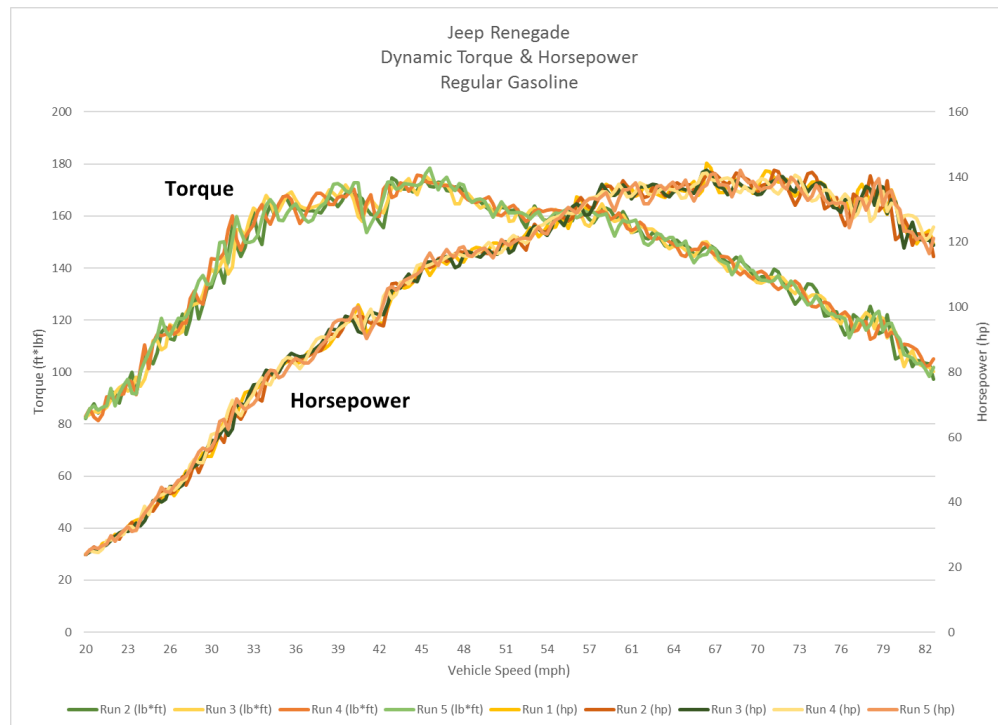


Figure 40: Jeep Renegade Dynamic Torque & Horsepower - All Runs on Regular Gasoline

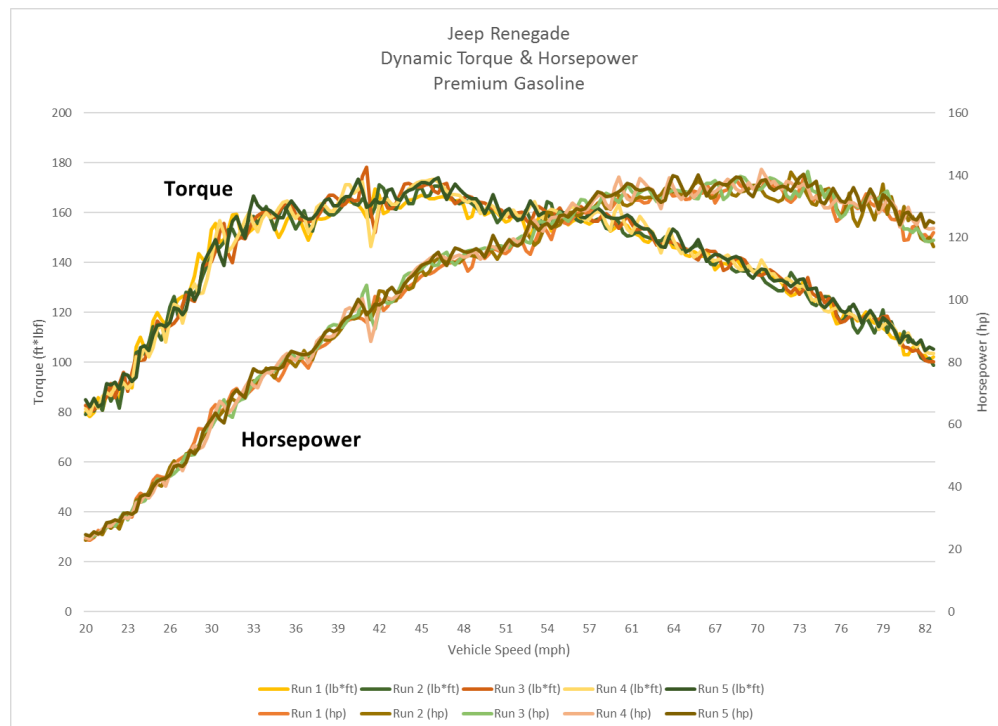


Figure 41: Jeep Renegade Dynamic Torque & Horsepower - All Runs on Premium Gasoline



13.7 Static Power Graphs

13.7.1 2017 Ford F150

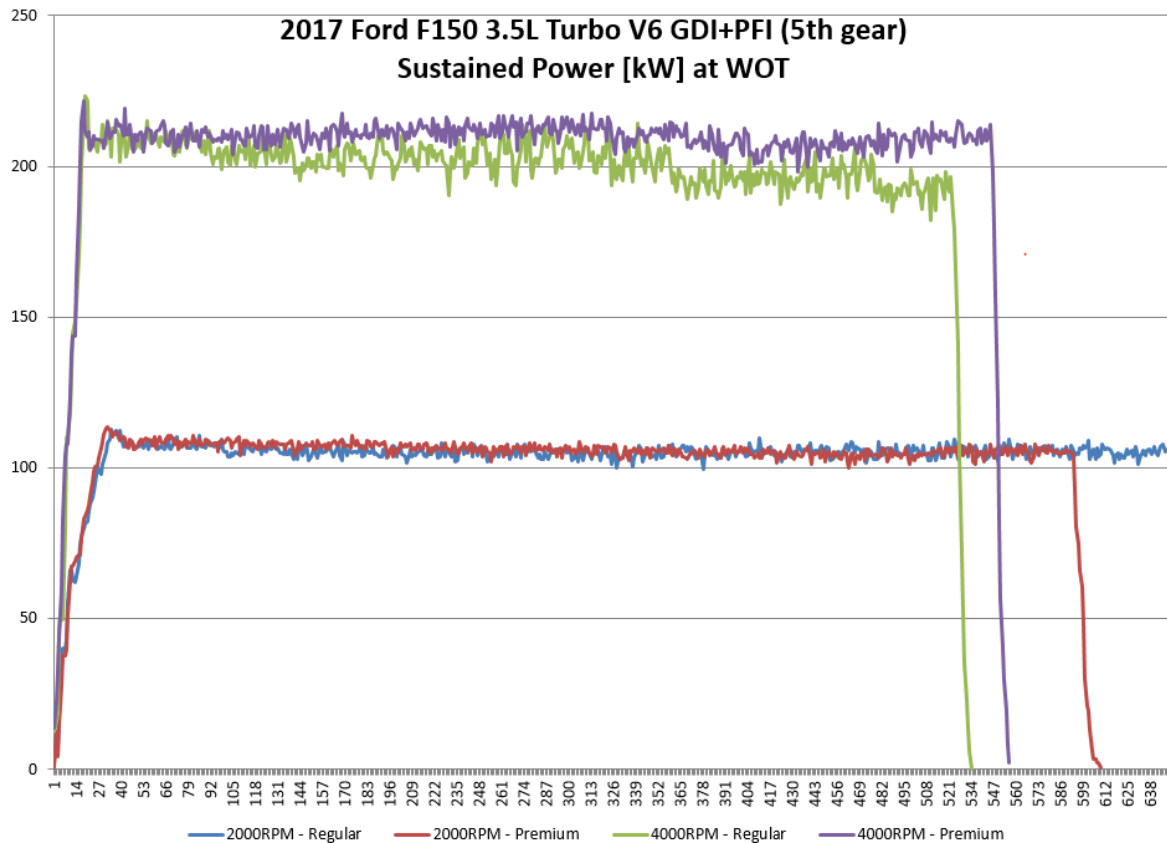


Figure 42: Ford F150 Static Power at 2000 and 4000 RPM



13.7.2 2016 Cadillac Escalade ESV

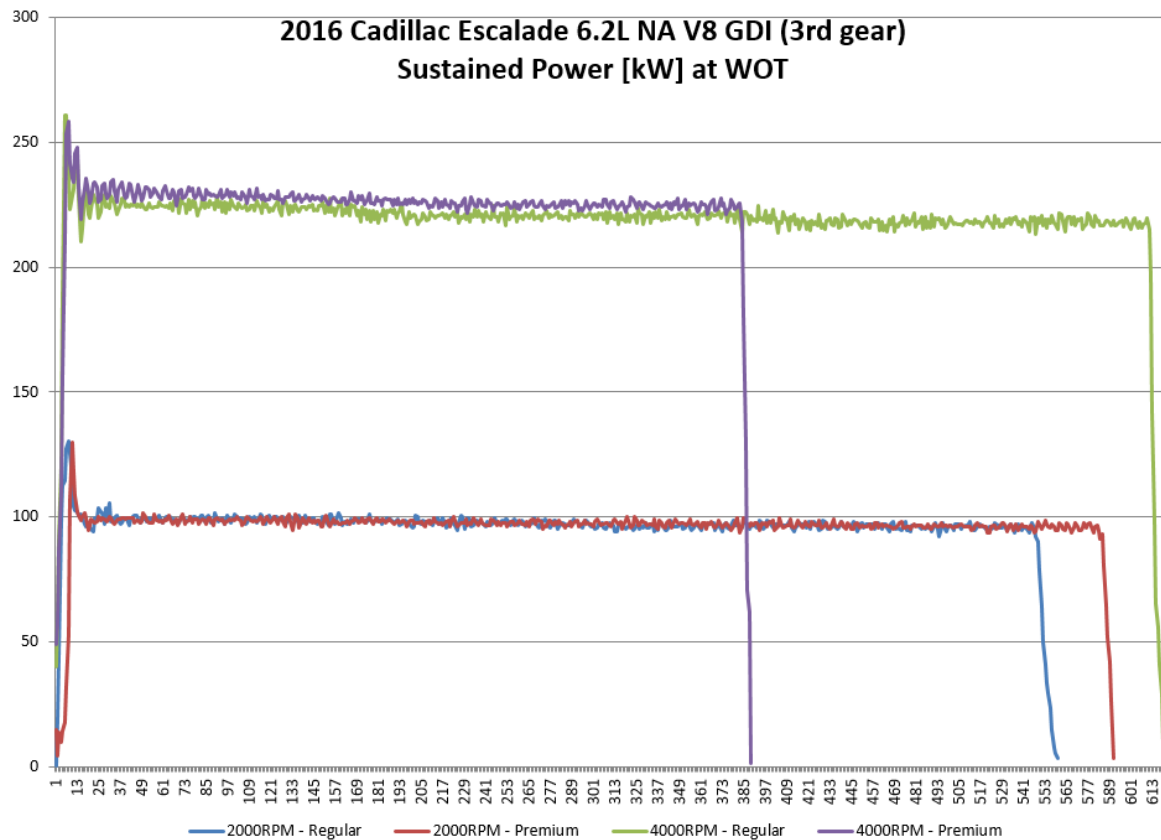


Figure 43: Cadillac Escalade ESV Static Power at 2000 and 4000 RPM



13.7.3 2015 Mazda Miata

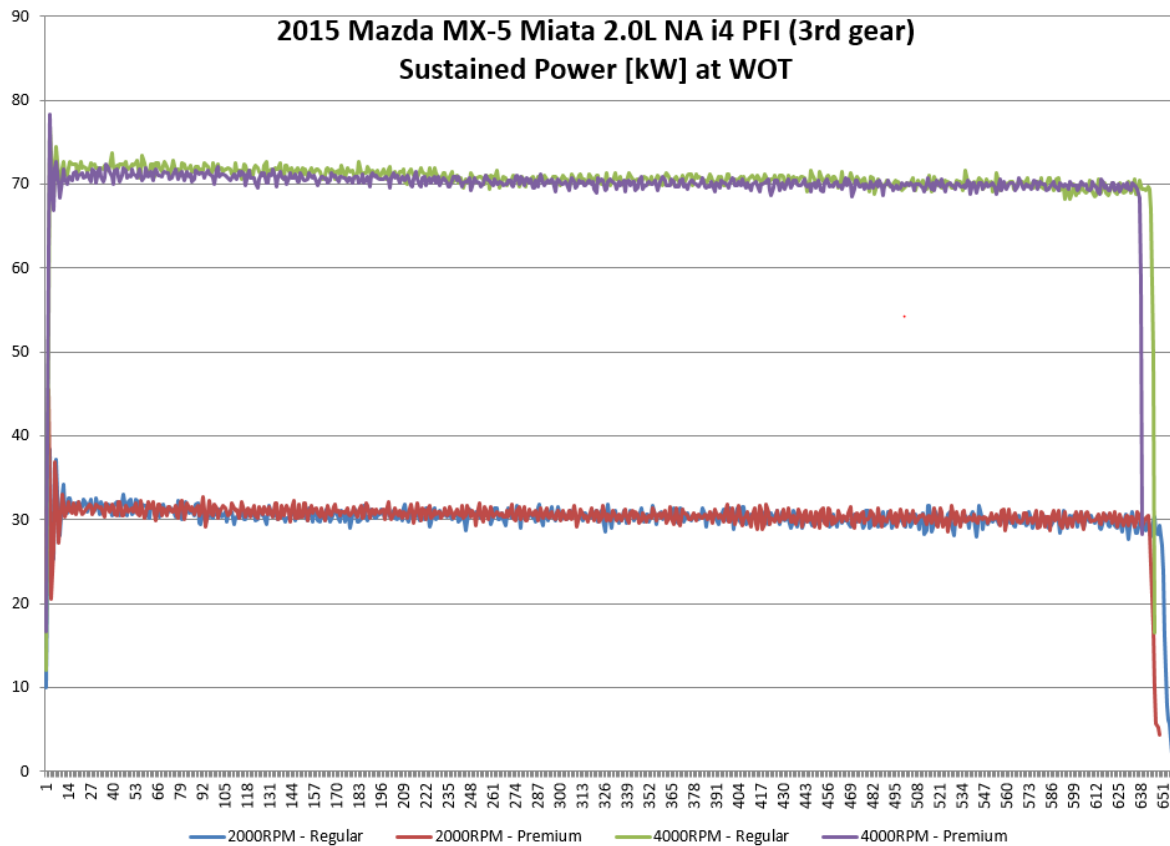


Figure 44: Mazda Miata Static Power at 2000 and 4000 RPM



13.7.4 2016 Audi A3

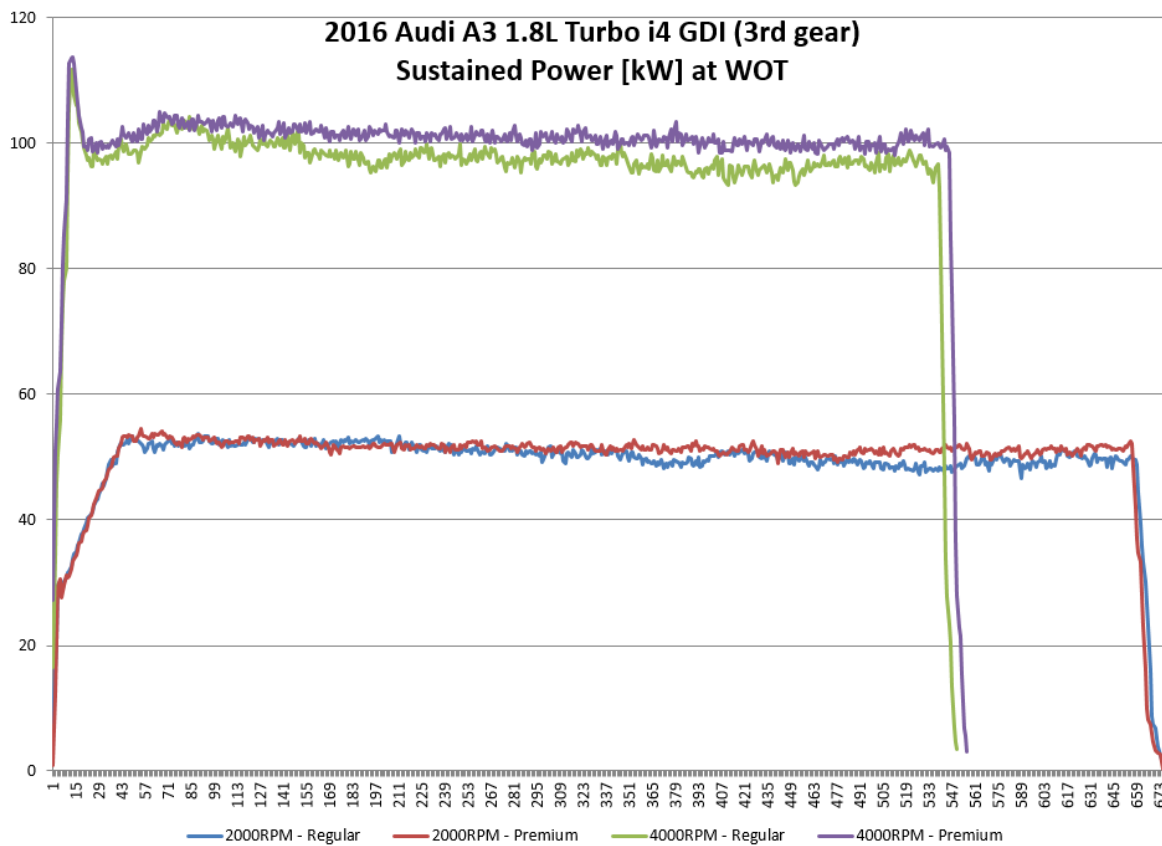


Figure 45: Audi A3 Static Power at 2000 and 4000 RPM



13.7.5 2017 Ford Mustang GT

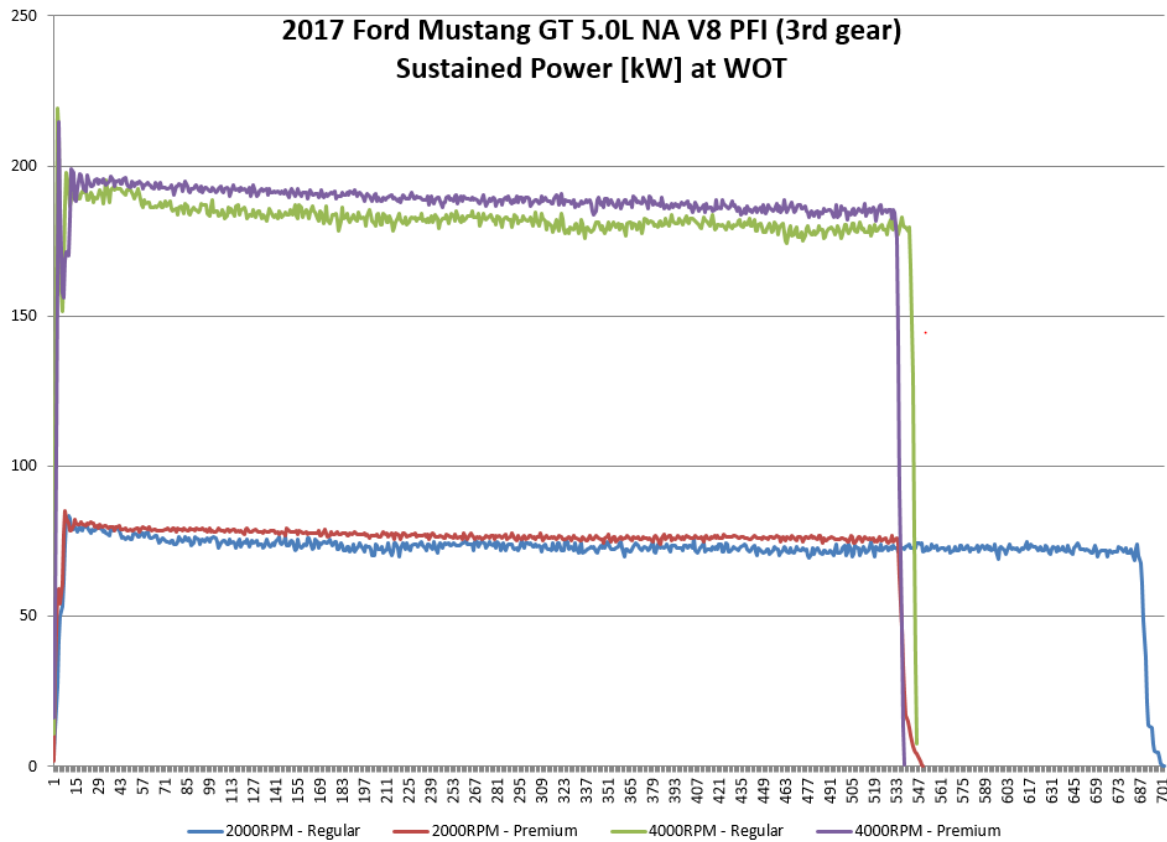


Figure 46: Ford Mustang GT Static Power at 2000 and 4000 RPM



13.7.6 2016 Jeep Renegade

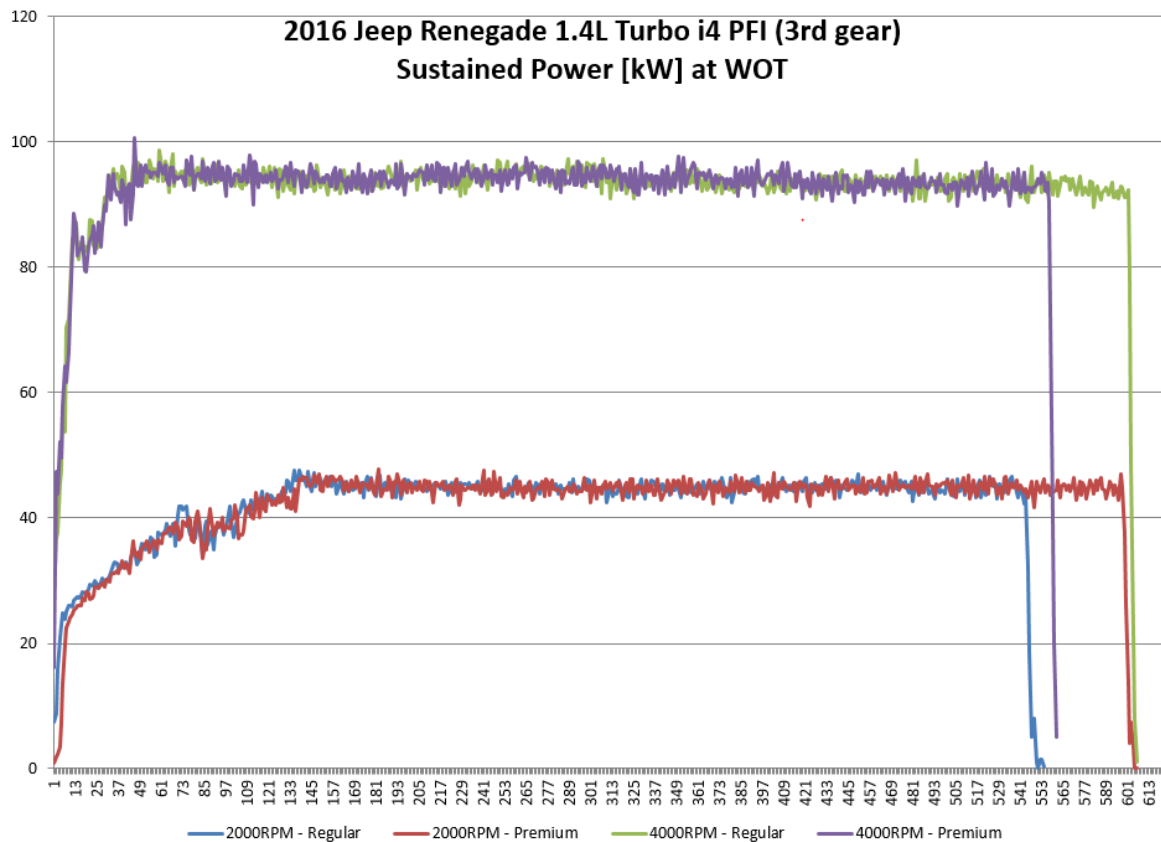


Figure 47: Jeep Renegade Static Power at 2000 and 4000 RPM



13.8 OBD Data Analysis

13.8.1 Ford F150

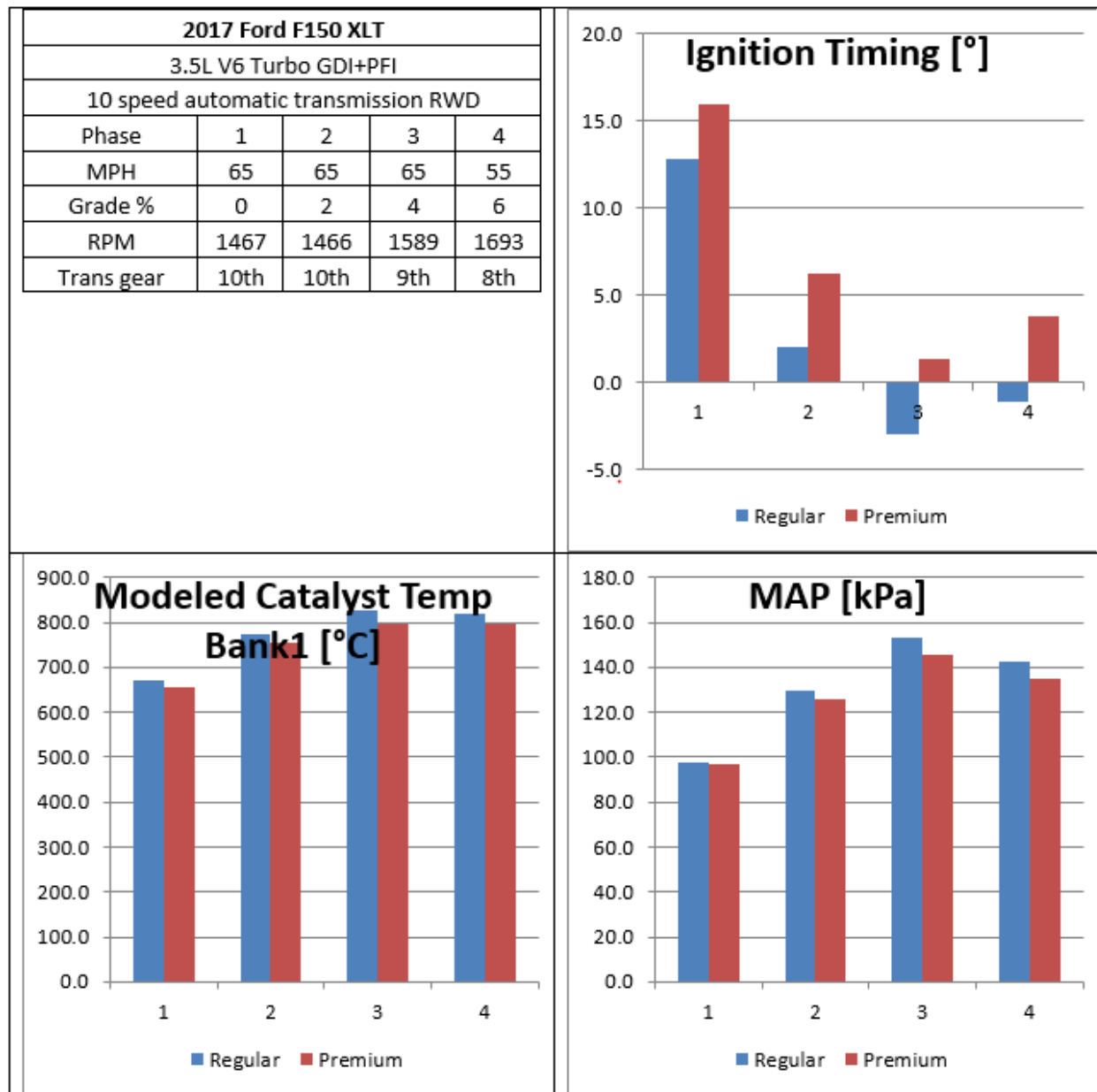


Figure 48: F150 OBD data comparison

13.8.2 Cadillac Escalade ESV

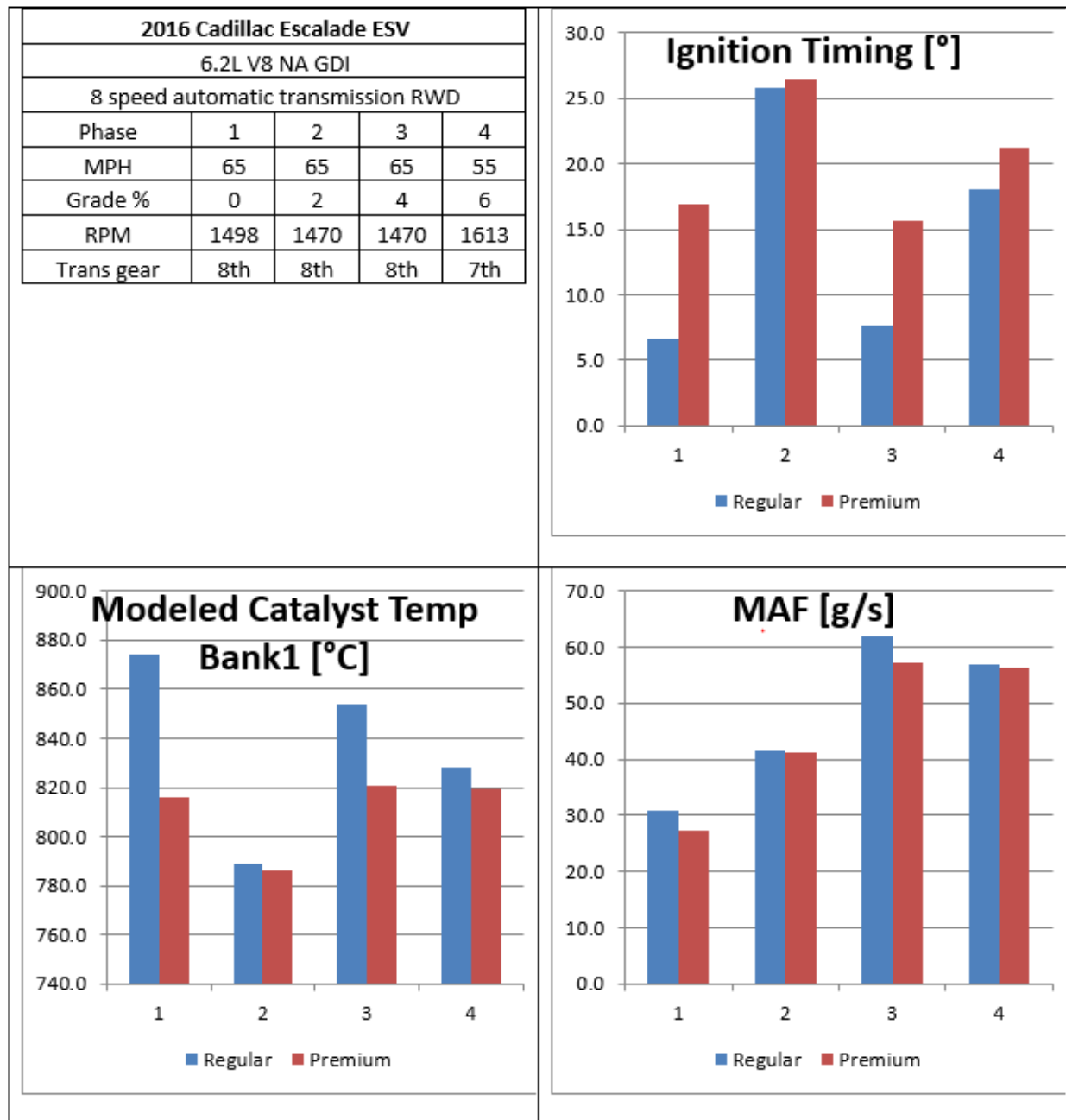


Figure 49: Cadillac Escalade ESV OBD data comparison



13.8.3 Mazda MX-5 Miata

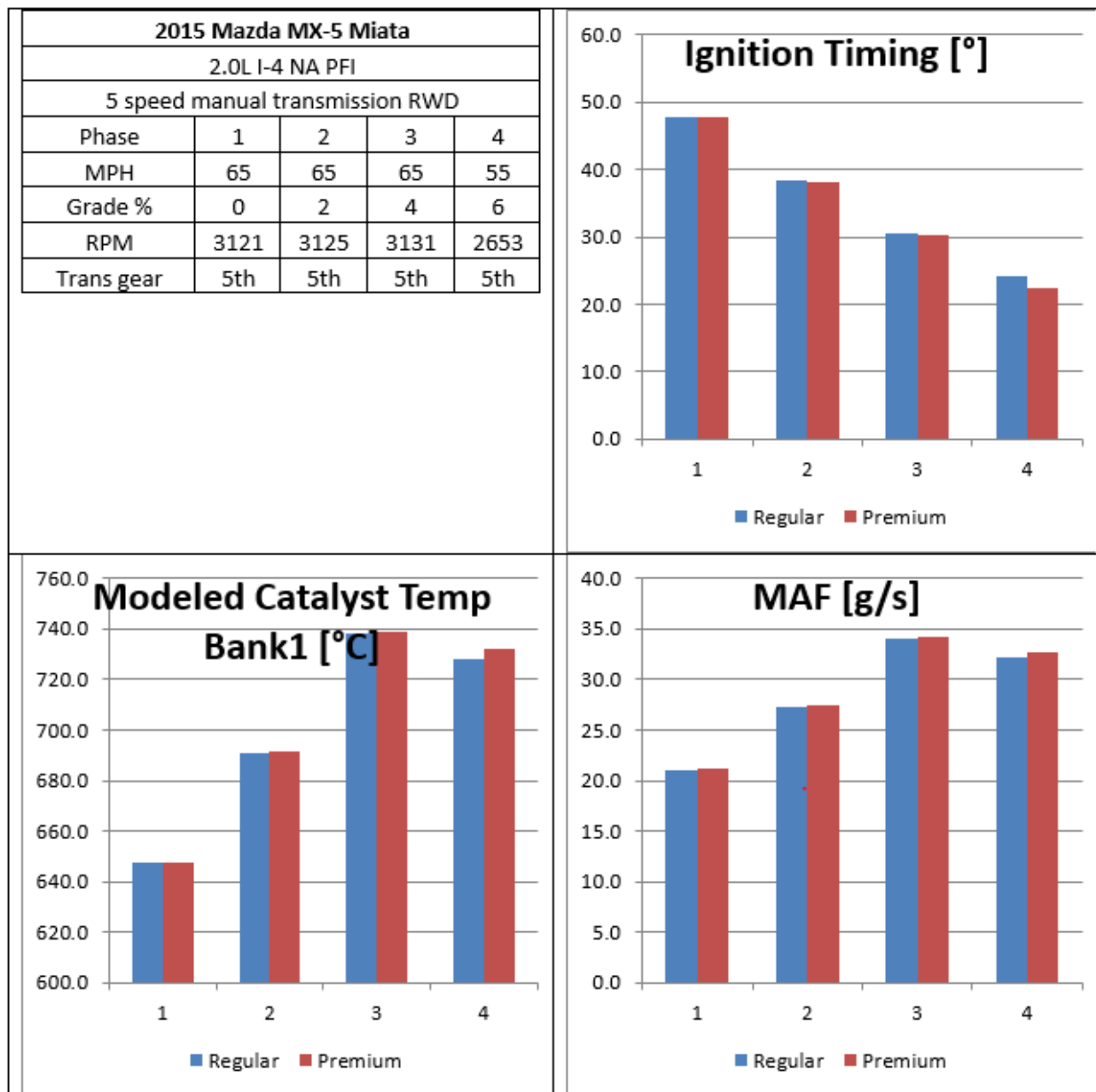


Figure 50: Mazda MX-5 Miata OBD data comparison



13.8.4 Audi A3

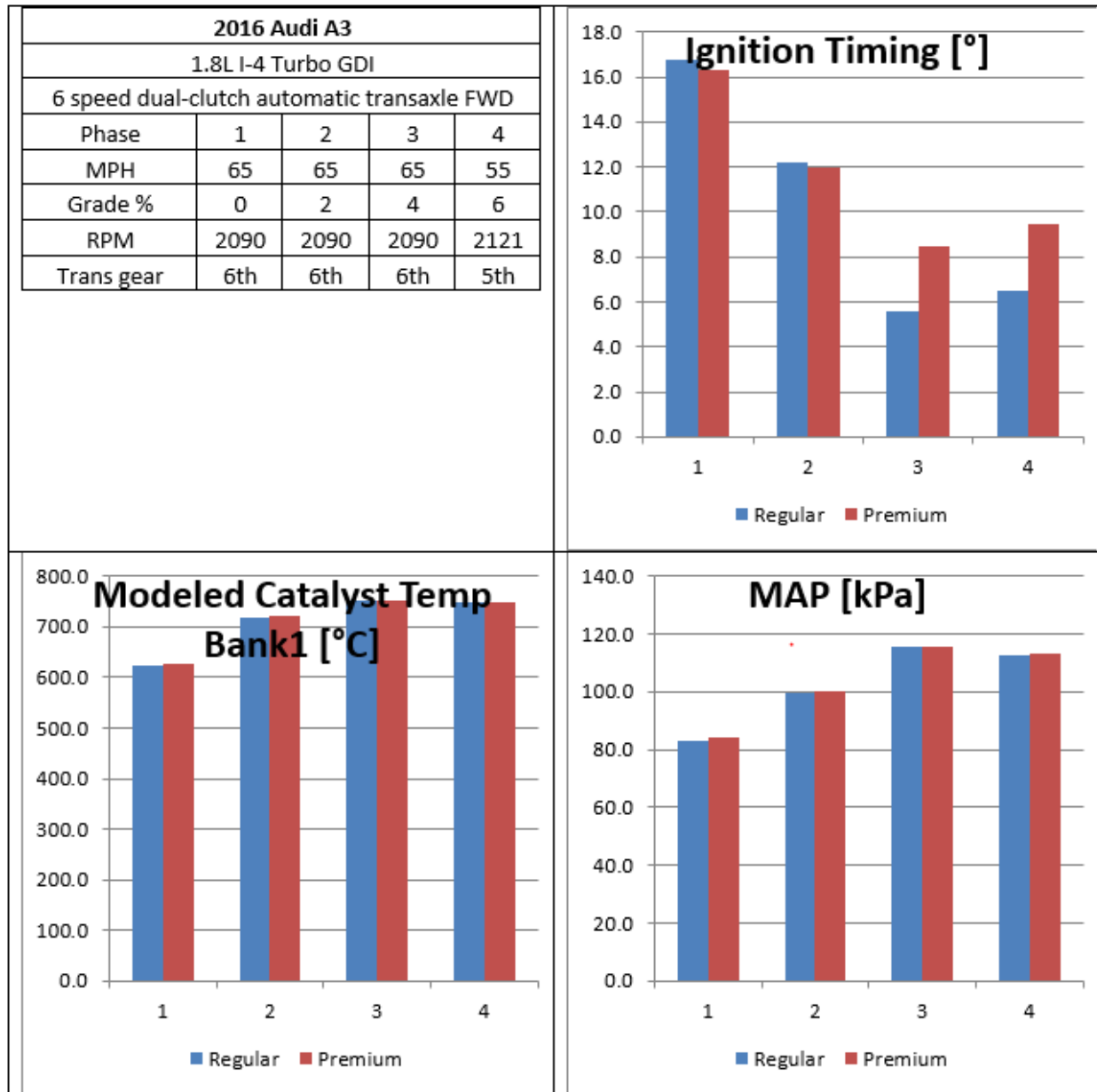


Figure 51: Audi A3 OBD data comparison



13.8.5 Ford Mustang GT

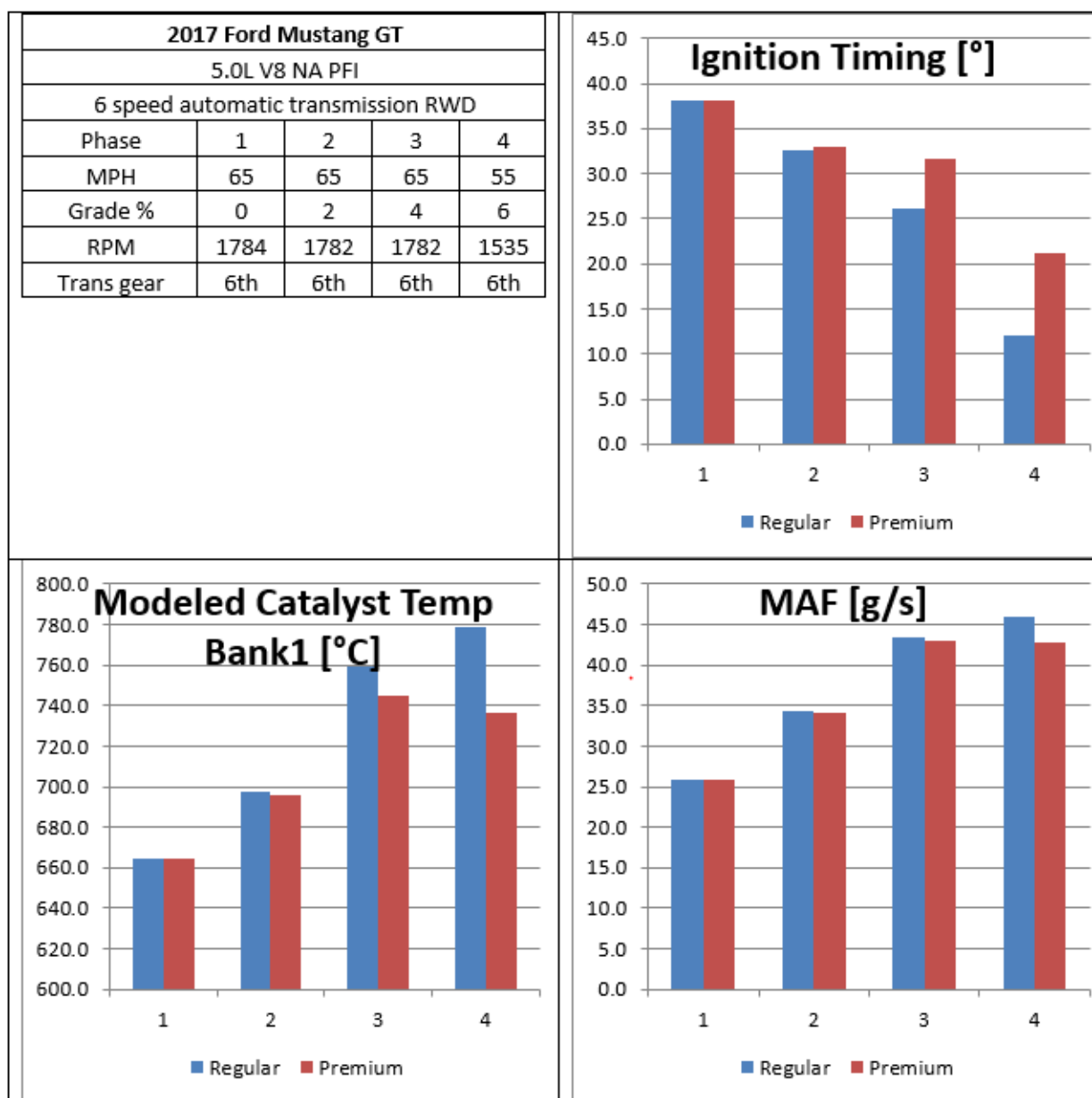


Figure 52: Ford Mustang GT OBD data comparison

13.8.6 Jeep Renegade

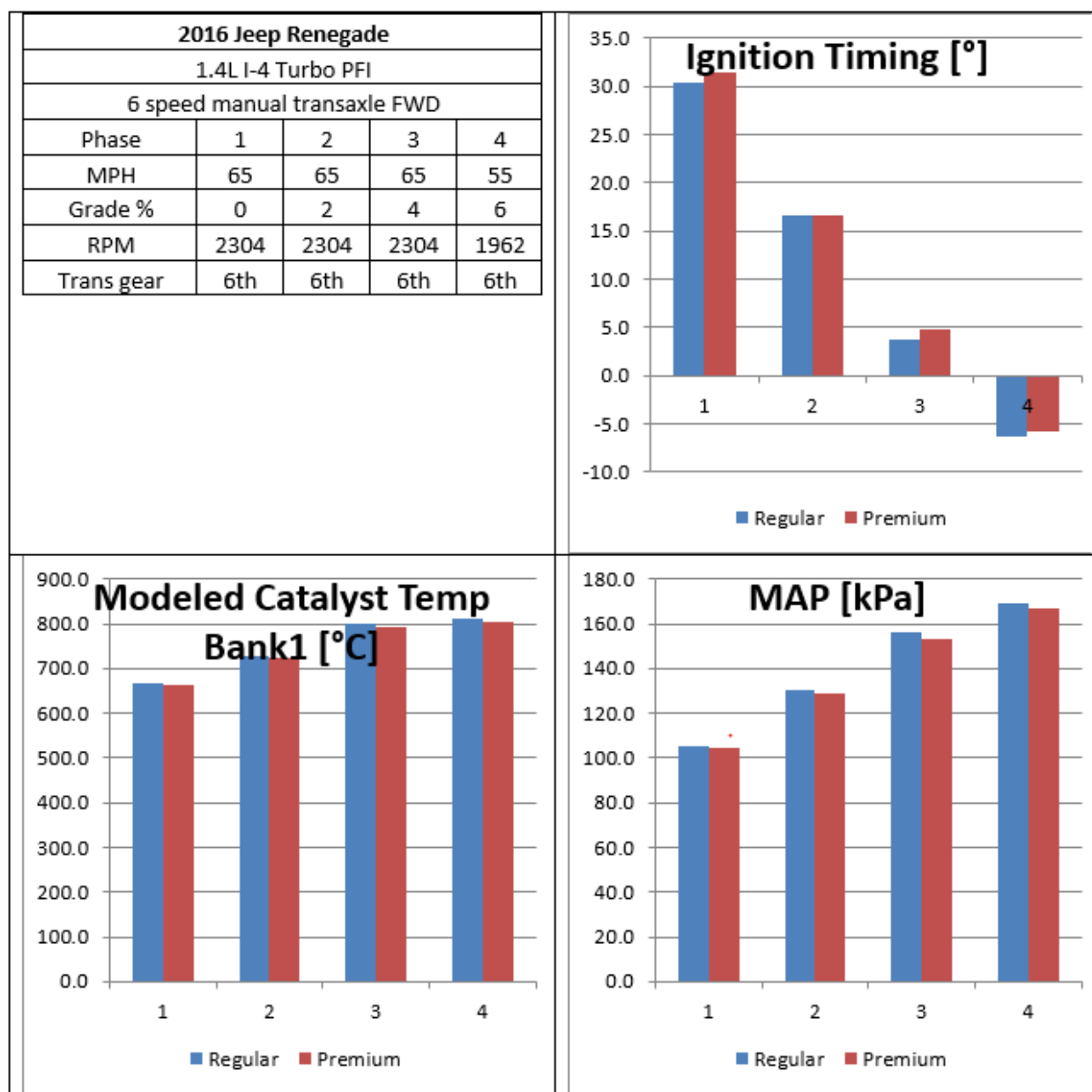


Figure 53: Jeep Renegade OBD data comparison



13.9 Explanation of annual fuel cost calculations

The calculations below are illustrative only. The actual test protocols used are not the same as those used to assign EPA fuel economy ratings.

An improvement in fuel economy can offset at least part of the additional cost to purchase premium gasoline.

One test vehicle averaged a 2.3% improvement when using premium gasoline.

EPA combined rating (regular)	Adjusted rating (+2.3%)
18	$18 \times 1.023 = \mathbf{18.4}$

Annual fuel cost calculation:

Miles driven per year	15,000
Regular	\$2.449
Premium	\$2.935

Annual fuel cost (regular)	$(\$2.449/18) \times 15,000 = \mathbf{\$2,041}$
Annual fuel cost (premium)	$(\$2.935/18) \times 15,000 = \mathbf{\$2,448}$
Additional cost for premium	\$407

With the improvement in fuel economy while using premium gasoline, the annual cost to select premium is reduced:

Annual fuel cost (regular)	$(\$2.449/18) \times 15,000 = \mathbf{\$2,041}$
Annual fuel cost (premium)	$(\$2.935/18.4) \times 15,000 = \mathbf{\$2,392}$
Additional cost for premium (with credit for improved mpg)	\$351

In this example, the extra cost to select premium fuel over 15,000 miles is reduced by \$56 due to improved fuel economy when using premium.



14 Bibliography

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