CRC Report No. 644

COMBUSTION CHAMBER DEPOSIT RESEARCH TOOL DEVELOPMENT

PART 2

ENGINE DYNAMOMETER TESTING

May 2005

COORDINATING RESEARCH COUNCIL, INC.
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The Coordinating Research Council, Inc. (CRC) is a non-profit corporation supported by the petroleum and automotive equipment industries. CRC operates through committees made up of technical experts from industry and government who voluntarily participate. The four main areas of research within CRC are: air pollution (atmospheric and engineering studies); aviation fuels, lubricants, and equipment performance, heavy-duty vehicle fuels, lubricants and equipment performance (e.g., diesel trucks); and light-duty vehicle fuels, lubricants, and equipment performance (e.g., passenger cars). CRC's function is to provide the mechanism for joint research conducted by the two industries that will help in determining the optimum combination of petroleum products and automotive equipment. CRC's work is limited to research that is mutually beneficial to the two industries involved, and all information is available to the public.

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COMBUSTION CHAMBER DEPOSIT RESEARCH TOOL DEVELOPMENT PART 2 ENGINE DYNAMOMETER TESTING

(CRC Project No. CM-136-98/CCD-3)

Prepared by the

CRC Combustion Chamber Deposit Program Panel
of the
Deposit Group

May 2005

CRC Performance Committee
of the
Coordinating Research Council, Inc.

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EXECUTIVE SUMMARY

The Coordinating Research Council, Inc. (CRC) conducted a two-phase study intended as a key step toward developing an engine test to use as a research tool for the evaluation of combustion chamber deposits (CCD) in spark-ignition automotive engines. Objectives of the program included (1) identification of an engine, test cycle, test duration for a dynamometer test or analytical bench test, and (2) verification of additive rankings of that bench test versus vehicles on the road in various fuels. This project built on the results of the previous programs conducted by CRC[1,2,3,4].

The first phase of the study, conducted at Southwest Research Institute (SwRI) and described in CRC Report No. 630[(1)], was an on-road vehicle test program to investigate and rank the CCD-forming characteristics of five fuels in two 1999-model vehicle types. The purpose of the SwRI vehicle phase of the study was to rank fuel additive performance in on-road vehicles to use as a baseline in evaluating the potential dynamometer or analytical bench test.

The second phase of the study, conducted at PerkinElmer Automotive Research (PEAR) and described in this report, had as its objective the identification of an engine/cycle/duration for a dynamometer test that ranks the additives in the same relative order as found in the on-road vehicles in the SwRI work.

The engines tested, the 4-cylinder 2.0-liter Dodge Neon from DaimlerChrysler and the V-8 6.0-liter Chevrolet Silverado from GM, were common to both the SwRI and PEAR phases. One of the five cycles used in the PEAR testing simulated as closely as possible the variation of the Modified Alternate Mileage Accumulation (MAMA) cycle used in the SwRI work. The five fuels tested were also common to both phases: an unadditized base fuel and that fuel with four different detergent additive packages. The additized fuels contained either a high-CCD-forming additive also used in a previous CRC CCD study (Fuel D), or one of three commercially available additive packages (Fuels A, B, and C), representative of current marketplace technology. One is a premium dose polyetheramine, one is a premium dose polyisobutylene amine (PIBA) with synthetic carrier, and one is an EPA lowest additive concentration (LAC) plus 10 percent PIBA with synthetic carrier. (Treating at 10 percent above LAC is a common practice.) These additives are not otherwise identified.

Analytical testing was also performed on the fuels using a thermal gravimetric analysis (TGA) procedure developed by Ford Motor Company. The procedure was developed to determine the propensity of a fuel to form CCD by analyzing the unwashed gums of gasoline.

Of the six dynamometer cycles evaluated, the one designated as the "MAMA" cycle provided slightly better ability to differentiate test fuels based on their total CCD weight. The CCD ranking pattern of the MAMA cycle was also similar to the vehicle data. However, the considerable improvement in operational and implementation simplicity as well as overall acceptable performance in differentiating fuels based on their CCD formation tendency are the overwhelming reasons that the group is recommending the Milder-10 (MLD-10) cycle as a research tool. Additionally, the Milder-10 (MLD-10) cycle matches the fuel consumption seen in the Dodge Neon vehicle tested on the road. In general, the vehicle data showed somewhat better discrimination than do the limited dynamometer data, but this could change with additional dynamometer testing.

The Ford TGA bench test appears to hold promise for predicting combustion chamber deposits of additized fuels, particularly in identifying fuel/additive combinations with high CCD potential. This test has potential for further development beyond what was accomplished in this program. It is recommended that additional data be added to the data set whenever possible and that the variability of the Unwashed Gum and TGA parameters be investigated.

I. INTRODUCTION

The importance of combustion chamber deposits (CCD) in spark-ignition automotive engines has increased over the past few years as the US Environmental Protection Agency (EPA) and the California Air Resources Board (CARB) have shown increasing interest in the potential relationship between fuel-related engine deposits and increased engine-out emissions. Simultaneously, the automotive manufacturers have been concerned not only about the emissions aspect, but also about the physical impact of CCD on the engine.

The Coordinating Research Council, Inc. (CRC) conducted a two-phase study intended as a key step toward developing an engine test procedure to use as a research tool for the evaluation of CCD in spark-ignition automotive engines. This project built on the results of the previous programs conducted by CRC.[1, 2, 3, 4]

The first phase of the study, conducted at Southwest Research Institute (SwRI) and described in CRC Report No. 630[(1)], was an on-road vehicle test program to investigate five fuels and rank their CCD-forming characteristics in two 1999-model vehicle types. The second phase of the study, conducted at PerkinElmer Automotive Research (PEAR) and described in this report, had as its objective the identification of an engine/cycle/duration for a dynamometer test that ranks the additive in the same relative order as found in the on-road vehicles in the SwRI work.

The engines tested, the 4-cylinder 2.0-liter Dodge Neon from DaimlerChrysler and the V-8 6.0-liter Chevrolet Silverado from GM, were common to both the SwRI and PEAR phases. The five fuels tested were also common to both phases. One of the cycles used in the PEAR testing simulated as closely as possible except for transitions between speeds the variations of the Modified Alternate Mileage Accumulation (MAMA) cycle used in the SwRI work.

It was decided to conduct the two phases of the program in parallel rather than sequentially because the heightened interest in CCD imposed time constraints for development of a test procedure to serve as a research tool for evaluation of the effects of CCD. While it would have been ideal to conduct the vehicle phase prior to the dynamometer phase and be able to draw from the vehicle driving patterns and results for the dynamometer test cycles, it was considered more important to lessen the time required for this program to provide industry with a suitable research tool. Conducting the program in this manner carried with it some degree of risk; that is, the information from the vehicle work could have directed the dynamometer development in a different direction. The CCD Program Panel circumvented some of the necessary investigation of engine and vehicle parameters by instrumenting the vehicles very early in their testing and obtaining the data necessary to develop the dynamometer test cycles.

Analysis of the fuels was done using a thermal gravimetric analysis (TGA) procedure developed by Ford Motor Company. The procedure was developed to determine the propensity of a fuel to form CCD by analyzing the unwashed gums of gasoline. The intent of these tests was to investigate the viability of using fuel analysis either alone or in addition to dynamometer testing to evaluate the CCD-forming characteristics of fuels.

Members of the CCD Program Panel are listed in Appendix A. A write-up of the original CCD program proposal and scope of work is given in Appendix B.

II. BACKGROUND

A. Summary of CRC Project E-6, "Effects of Combustion Chamber Deposits on Vehicle Emissions and Fuel Economy"

Over the past few years, CRC has conducted studies on the effects of CCD on NOx emissions, surveyed in-use vehicles to find their levels of deposits, and examined the effects of engine operating conditions on deposit build-up(2,3,4). The program on engine operating conditions generated data to find the cycle, test length, and other conditions that would lead to an engine dynamometer test.

The primary goal of the CRC E-6 Project was to determine the relationship of CCD to vehicle emissions(2). Seven 1996 model year vehicles of each of four vehicle models (Dodge Caravan, Dodge Neon, Ford Crown Victoria, and Oldsmobile 88) were run for 15,000 miles to accumulate deposits using three fuels: a base fuel without deposit control additives and the base fuel with two different additive treatments.

It was not possible to reach a definitive conclusion about the shape of the emissions versus CCD relationship because the mid- and high-CCD-forming fuels produced almost the same level of CCD. Large vehicle model-to-model differences in the CCD levels produced by the three fuels also complicated data analyses; average CCD mass per engine cylinder produced by the additized fuels was 1.2 to 5 times the levels produced by the base fuel in the four vehicle models tested.

These difficulties notwithstanding, it was concluded that the FTP composite tailpipe and engine-out NO_x and CO_2 emissions and fuel economy increment means for the additized fuels were significantly different from the means produced by the base fuel. CO_2 increment means were significantly different for all of the individual FTP bag analyses. These increment means show that higher CCD levels result in increases in NO_x emissions and fuel economy. None of the other emission variates showed a statistically significant increment difference between the additized and base fuels. (The increment model used in the E-6 Program was the 15,000-mile results minus the average of the 0-mile results from the test segment and the 0-mile results from the next test segment.)

B. Summary of "Combustion Chamber Deposit Research Tool Development: Part 1 - Vehicle Deposits and Emissions"

The SwRI vehicle phase of the current study had some common threads with the E-6 Project. The Dodge Neons (although 1999-model year versus 1996-model year), the base fuel (albeit of a different manufacturing batch), the mileage accumulation driving schedule (road in the SwRI study versus track in the E-6 program), the mileage accumulation interval, and the high-CCD reference additive used in Fuel D are all common between the SwRI phase of the current program and the earlier E-6 Project.

Five fuels were tested in the current two-phase study: an unadditized base fuel and that fuel with four different detergent additive packages. The base fuel (Fuel E) was unadditized RF-A, defined by the Auto/Oil Air Quality Improvement Program to be the average US fuel in 1989. In addition, batches of fuel made to these same specifications have been used in previous CCD programs. The specifications, certificate of analysis, and inspection data from PEAR for this fuel are detailed in Appendix D. The remaining four fuels were the base fuel additized with four different additives provided by the petroleum companies on the CCD Program Panel. Fuel D contained the high-CCD-forming additive used in the previous E-6 Program. Fuels A, B, and C each contained commercially available additive representative of current marketplace technology: one premium dose polyetheramine, one premium dose PIBA with synthetic carrier fluid, and one regular dose lowest additive concentration (LAC) plus 10 percent (a common practice) PIBA with synthetic carrier fluid. (The alphabetical order does not necessarily align with the descriptions.) The premium dose PIBA/synthetic additive was from a different supplier than the LAC PIBA/synthetic additive.

The Alternate Mileage Accumulation (AMA) Durability Driving Schedule for Light-Duty Vehicles and Light-Duty Trucks is defined in the Federal Register(5). This schedule had been modified in previous CCD programs (i.e., the CRC E-6 Project) to eliminate the wide-open-throttle and hard accelerations because of concern that such procedures might dislodge CCD. The E-6 variation of the Modified AMA (MAMA) cycle was further modified for the SwRI work to the extent required for executing it on the public roads in the area of SwRI. This variation of the MAMA cycle used consists of approximately 11 miles of 30-mph driving with light accelerations, 4 miles of 40-mph driving with light accelerations, 4 miles of 55-mph driving with moderate accelerations, 15 miles of 60-mph driving with moderate accelerations, and 26 miles of 70-mph driving with moderate accelerations.

Deposit measurements in the SwRI phase included CCD weight determinations, CCD thickness measurements, and intake valve deposits (IVD) boroscope ratings. Table 1, taken from the Part 1 Report, summarizes these deposits rankings and the statistical significance of the deposit level differences among the test fuels. For each vehicle type the fuel-additive combinations are given in rank order: heaviest to lightest for CCD Total Weight, thickest to thinnest for CCD Average Thickness, and highest visual rating (lowest valve deposits) to lowest rating (heaviest deposits) for IVD Boroscope Ratings.

The vertical bars ("|") indicate those that are not significantly* different. As can be seen in Table 1, the two vehicles rank the fuel/additives in the same order for CCD Total Weight, but the statistical significance of the differences among the fuel/additives is not the same. For CCD Average Thickness, the rankings and the statistical significance are not the same for the two vehicles and there are some significant performance differences among the commercial additives. For IVD, the rankings are nearly the same for the two vehicle types with significant differences among the fuel/additives being the same. One of the commercial additive packages (Fuel C) performed significantly poorer than the other commercial packages. The separation in these performance parameters in the vehicle test program provides a basis for comparing the CCD results to the engine dynamometer test development work.

Table 1

Summary of the Rankings and Significance* of CCD Weight, CCD Thickness, and IVD Ratings for the Part 1 Vehicle Test Program (Table 1 from the Part 1 Report)

<table>
<tr><th></th><th colspan="3">Chevrolet Silverado 6.0 L</th><th colspan="5">Dodge Neon 2.0 L</th><th></th></tr>
<tr><th></th><th>Rank</th><th colspan="2">Significance</th><th colspan="4"></th><th></th><th></th></tr>
<tr><td rowspan="5">CCD Weight</td><td>D</td><td></td><td></td><td></td><td></td><td></td><td>|</td><td>D</td><td>Heaviest</td></tr>
<tr><td>A</td><td>|</td><td></td><td></td><td></td><td>|</td><td>|</td><td>A</td><td></td></tr>
<tr><td>C</td><td>|</td><td></td><td></td><td></td><td>|</td><td></td><td>C</td><td></td></tr>
<tr><td>B</td><td>|</td><td></td><td></td><td></td><td>|</td><td></td><td>B</td><td></td></tr>
<tr><td>E</td><td></td><td></td><td></td><td></td><td></td><td></td><td>E</td><td>Lightest</td></tr>
<tr><td rowspan="5">CCD Thickness</td><td>D</td><td></td><td></td><td></td><td></td><td></td><td>|</td><td>D</td><td>Thickest</td></tr>
<tr><td>A</td><td></td><td></td><td></td><td></td><td>|</td><td>|</td><td>A</td><td></td></tr>
<tr><td>B</td><td></td><td>|</td><td></td><td>|</td><td>|</td><td></td><td>C</td><td></td></tr>
<tr><td>C</td><td></td><td>|</td><td>|</td><td>|</td><td></td><td></td><td>B</td><td></td></tr>
<tr><td>E</td><td></td><td></td><td>|</td><td></td><td></td><td></td><td>E</td><td>Thinnest</td></tr>
<tr><td rowspan="5">IVD Rating</td><td>B</td><td></td><td>|</td><td></td><td></td><td></td><td>|</td><td>D</td><td>Lowest Deposits</td></tr>
<tr><td>D</td><td></td><td>|</td><td></td><td></td><td></td><td>|</td><td>A</td><td></td></tr>
<tr><td>A</td><td></td><td>|</td><td></td><td></td><td></td><td>|</td><td>B</td><td></td></tr>
<tr><td>C</td><td>|</td><td></td><td></td><td></td><td>|</td><td></td><td>C</td><td></td></tr>
<tr><td>E</td><td>|</td><td></td><td></td><td></td><td>|</td><td></td><td>E</td><td>Heaviest Deposits</td></tr>
</table>

* "Significance" in this table means the comparison was found to be statistically significant with alpha = 0.05. This is sometimes called the 95% "Confidence Level".

To aid in interpreting Table 1, pairs of fuels that do not share a "|" in the same column were significantly different from each other. For example, in the Silverado for CCD total weight, Fuel D was significantly different from all other fuels, Fuel E was significantly different from all other fuels, and Fuels A, C, and B were **not** significantly different from each other. In the Neon for CCD total weight, Fuel D was significantly different from Fuels C, B, and E but was **not** significantly differently from Fuel A. Fuels A, C, and B were **not** significantly different from each other. Fuel E was significantly different from all other fuels.

Figures 5 and 11 from CRC Report No. 630[1] on the SwRI work, reproduced in this report as Figures 1 and 2, show the CCD total weight for each vehicle model. In these two figures the alpha level for the error bars is 0.05. This is sometimes called the 95 percent "Confidence Level." For the Chevrolet Silverado, Fuel E (base fuel) deposit weights are significantly lower than for Fuels A, B, and C (commercial additive packages). Fuels A, B, and C, those with commercial additives, produced deposits not significantly different from each other. Fuel D (high-CCD-forming additive from the previous E-6 study) produced the heaviest CCD total weight, which was significantly higher than the other fuels. The increases over base fuel for the commercial packages range from 59 percent (Fuel B) to 89 percent (Fuel A) for the GM Chevrolet Silverados, compared with 139 percent for Fuel D. For the Dodge Neon vehicles, Fuel E deposit weights are significantly lower than for the other fuels. Fuel D produced the heaviest deposits and these are significantly higher than those from Fuels C, B, and E but are not significantly different than those from Fuel A. The deposits from Fuels A, B, and C are not significantly different from each other. The increases over base fuel range from 57 percent (Fuel B) to 82 percent (Fuel A), compared with 118 percent for Fuel D.

No consistent statistically significant differences in exhaust emissions were found for any of the emissions parameters (non-methane hydrocarbons, carbon monoxide, nitrogen oxides, and fuel economy) due to differences between fuel additives or due to differences in CCD deposit levels with the vehicles, fuels, and number of tests in the SwRI vehicle phase, although several statistical approaches were used. This is illustrated in Figures 3 and 4 (Figures 33 and 37 from the Part 1 Report) for the NO_x increment data for each vehicle type. The increments used are the same as the E-6 program, the 15,000 mile results minus the average of the 0-mile results from the test segment and the 0-mile results from the next test segment. When the intervals overlap, the differences among the fuels are not significant with alpha = 0.05.

Fuel D (containing the high-CCD-forming additive) and Fuel E (base fuel) were common in the Dodge Neon vehicle with the previous E-6 emissions study. The results from the two programs are compared in Figure 5, CCD Total Weight, Figure 6, CCD Average Thickness, and Figure 7, Boroscope IVD Ratings. Although the emissions calibration of the Neons differed between the two programs (California versus federal), the deposit measurements from the SwRI program were generally consistent with the results from the E-6 program. In general, the comparison between the two projects is viewed favorably. This suggests that laboratory-to-laboratory differences, fuel batch-to-batch differences, and the road versus track differences have not resulted in major shifts in the deposit results.

III. PART 2: ENGINE DYNAMOMETER TESTING

The engine dynamometer phase of the study was conducted at PerkinElmer Automotive Research (PEAR) from mid-2000 through late 2003. The final report of PerkinElmer Automotive Research on the engine dynamometer phase is given in

Appendix C. The engines tested, the 4-cylinder 2.0-liter Dodge Neon from DaimlerChrysler and the V-8 6.0-liter Chevrolet Silverado from GM, were common to both the SwRI and PEAR phases. Two Neon and two GM engines were provided gratis by DaimlerChrysler and GM, and were installed on engine dynamometers at PEAR. DaimlerChrysler and GM worked closely with PEAR during the installation and set-up.

Both the Neon and GM engines supplied to PEAR were taken from the respective assembly lines for the dynamometer tests. Both DaimlerChrysler and GM supplied special wiring harnesses and modified electronic control modules (ECMs) for use on the engine dynamometers. The GM engines were 1999 models; however, DaimlerChrysler had already converted their assembly line to the 2000 model-year engines. The SwRI vehicle phase of the testing had used all 1999 models. The 2000 model-year Neon engines did not include exhaust gas recirculation (EGR), while the 1999 vehicles did have EGR, and had other changes compared with the 1999 models used in the vehicle testing.

Additional cylinder heads and engines were purchased, along with intake and exhaust valves, rebuild kits, and spare parts. Cylinder heads were alternated for each test start on each engine. The engine blocks were replaced every 10 tests, and the heads every 5 tests, unless mechanical failure or excess wear were indicated.

The motor oil used was supplied from the new batch of ASTM D 6201 Intake Valve Deposit Test motor oil. Oil consumption was monitored during the test, and the oil was changed every 100 hours. The oil fills and drains were weighed to determine consumption, and that value was converted to ounces.

The five fuels tested were also common to both phases. The fuels are described in detail on page 5 of this report. The base fuel was purchased as a single batch to conduct the entire vehicle and dynamometer program. The remaining four fuels were the base fuel additized with four different additives.

Deposit measurements made in the PEAR dynamometer phase were the same as in the SwRI vehicle phase: IVD, CCD thickness measurements, and CCD mass determinations. At the end-of-test (EOT), PEAR removed the cylinder head and took it to a temperature- and humidity-controlled environment. Every effort was made to remove the head within 24 hours of EOT to minimize deposit flaking. With the head removed, the rater visually rated piston tops, cylinder bore surfaces, valve faces, and intake runners. Intake valves were then removed and both deposit weights and valve tulip ratings were determined. CCD thickness measurements were then taken using a Permascope® and a template supplied by SwRI. The piston tops and cylinder head surfaces were then scraped, and all deposits were collected and weighed. Finally, the valves were cleaned and weighed per the ASTM D 6201 Intake Valve Deposit Test Procedure. It was found that CCD thickness measurements and IVD weights were affected by operator technique at PEAR, causing variability in the results. This is especially pertinent with the first four tests with the Chevrolet Silverado engine and tests

DC2-30-0030, DC2-31-0031, and DC2-32-0032 with the DC Neon engine. It is, therefore, recommended that those data be viewed with some caution.

Six dynamometer test cycles were evaluated during the PEAR phase of the program in an attempt to match the performance and degree of CCD discrimination observed with the SwRI vehicle tests. These test cycles are designated as: (1) MAMA; (2) Simple; (3) MAMA with Soaks; (4) Milder; (5) Milder-10; and (6) Simple-15.

Engine Test Cycles

The **MAMA** cycle (Figure 8) was common between the PEAR and SwRI phases of the study, and was designed to replicate the SwRI road test cycle. The engine dynamometer version of the MAMA was based on data collected from the vehicles at the beginning of the SwRI phase. The major differences in the cycle for the dynamometer were removal of "key-off" events (which were replaced by idle periods), and the use of relatively fast (6-second) accelerations or ramps from idle to steady-state conditions. There were a series of ramps and steady-state segments over a two-hour period. Oil and coolant temperatures for each segment were based on the vehicle data, and the engine was controlled to revolutions-per-minute (RPM) and throttle-position-sensor (TPS) location.

The "**Simple**" test cycle (Figure 9) was designed to be very similar to the MAMA cycle, but with considerably fewer acceleration and deceleration ramps, to provide a simpler test cycle more easily adaptable by individual test laboratories. This cycle was based on the same steady-state conditions from the vehicles, but it only had eight steady-state segments over a one-hour period, compared with 63 for the MAMA cycle. The ramps from idle to steady state were the same 6-second ramps.

The "**MAMA Cycle with Soaks**" was a modification of the MAMA cycle to run 16 hours, followed by an overnight soak. The intent of this cycle was to simulate the vehicle key-off soaks, with the idea this may influence the CCD morphology and/or flaking process. Twelve tests were run with this cycle to give three results each on four of the five fuels. Fuel B was omitted since its results were considered similar to another fuel.

Four tests were conducted with the "**Milder**" cycle (Figure 10), which removed most of the higher mile-per-hour steady-state conditions and reduced the number of cycles to five to simplify programming. These tests with Fuels D and E produced higher total CCD weight, however, and this cycle was discontinued.

The "**Milder-10**" cycle (Figure 11) was designed to duplicate the fuel consumption values of the vehicles. This is abbreviated as **MLD-10** in some of the data tables and charts. The MAMA cycle on the dynamometer used about 60% more fuel than the vehicles, and the Simple cycle used about 20% more. The Milder-10 cycle had five steady-state conditions and decreased the speed of the ramps from idle to steady-state from 6 seconds to 10 seconds. The cycle name is a reflection of this 10-second ramp. The slower ramps allowed the engine to attain the desired steady-state condition with minimal or no overshooting of the target, whereas in the previous three cycles, the ramps were to a plateau, then a ramp down to the stage set points. These slower ramps were less severe on the engine/dynamometer linkage.

The "**Simple-15**" cycle (Figure 9) was similar to the Simple cycle with the ramps from idle to steady-state changed to 15-seconds from 6 seconds. This cycle had lower fuel consumption than the vehicles, and only two tests were conducted under these conditions.

Table 2 summarizes each of the six cycles tested on the dynamometer.

Table 2

SUMMARY OF DYNAMOMETER CYCLES

MAMA	Simple	MAMA with Soaks	Milder	Milder-10	Simple-15
Idle, 120 seconds	Idle, 120 seconds	Identical to MAMA Cycle	Idle, 80 seconds	Idle, 80 seconds	Identical to Simple Cycle, but
20 mph, 120 seconds	20 mph, 120 seconds	except for software modification	30 mph, 620 seconds	30 mph, 620 seconds	with 15-second ramps between
Idle, 180 seconds	Idle, 240 seconds	to run 16 hours, then be off for	Idle, 80 seconds	Idle, 80 seconds	stages, rather than 6-second
	60 mph, 215 seconds	8 hours.	70 mph, 620 seconds	70 mph, 620 seconds	ramps. There was a very minor
Repeat next	Idle, 240 seconds		Idle, 80 seconds	Idle, 80 seconds	change to the final idle time
sequence 8 times:	70 mph, 215 seconds		30 mph, 620 seconds	30 mph, 620 seconds	length (approximately 40 seconds) to
60 mph, 75 seconds	Idle, 20 seconds		Idle, 80 seconds	Idle, 80 seconds	correct for the lost seconds while
Idle, 15 seconds			40 mph, 620 seconds	40 mph, 620 seconds	keeping the cycle at a one-hour
	Repeat next		Idle, 80 seconds	Idle, 80 seconds	length.
Repeat next	*sequence 2 times:*		30 mph, 620 seconds	**60 mph, 620 seconds**	
sequence 2 times:	30 mph, 120 seconds				
70 mph, 1000 seconds	Idle, 20 seconds				
Idle, 45 seconds					
	40 mph, 120 seconds				
55 mph, 220 seconds	Idle, 20 seconds				
Idle, 300 seconds	40 mph, 900 seconds				
	Idle, 30 seconds				
Repeat next	30 mph, 900 seconds				
sequence 11 times:	Idle, 30 seconds				
30 mph, 45 seconds					
10 mph, 10 seconds					
30 mph, 45 seconds					
Idle, 15 seconds					
Repeat next					
sequence 5 times:					
40 mph, 20 seconds					
20 mph, 10 seconds					
40 mph, 20 seconds					
Idle, 20 seconds					
55 mph, 210 seconds					
Idle, 300 seconds					
60 mph, 75 seconds					
Idle, 20 seconds					
55 mph, 300 seconds					
Idle, 63 seconds					

The original experimental matrix for the engine dynamometer testing with randomized sequencing, using the MAMA and Simple test cycles, is shown in Table 3.

Table 3

CRC COMBUSTION CHAMBER DEPOSIT TEST DEVELOPMENT PROGRAM
EXPERIMENTAL DESIGN WITH RANDOMIZED SEQUENCE

Fuels

A: Commercial Fuel Additive A
B: Commercial Fuel Additive B
C: Commercial Fuel Additive C
D: High CCD Reference Additive from ATL emissions study
E: Base Fuel (RF-A)

		Engine Dyno Testing										
	GM						Neon					
Sequence	**Stand 1**			**Stand 2**			**Stand 3**			**Stand 4**		
	Block 1			**Block 2**			**Block 5**			**Block 6**		
	Head	**Fuel**	**Cycle**	**Head**	**Fuel**	**Cycle**	**Head**	**Fuel**	**Cycle**	**Head**	**Fuel**	**Cycle**
1	**1**	**B**	**MAMA**	**3**	**A**	**SIMPLE**	**9**	**D**	**MAMA**	**11**	**E**	**SIMPLE**
2	**2**	**D**	**SIMPLE**	**4**	**B**	**MAMA**	**10**	**A**	**SIMPLE**	**12**	**C**	**MAMA**
3	**1**	**A**	**MAMA**	**3**	**E**	**SIMPLE**	**9**	**C**	**MAMA**	**11**	**D**	**SIMPLE**
4	**2**	**B**	**SIMPLE**	**4**	**E**	**MAMA**	**10**	**D**	**SIMPLE**	**12**	**A**	**MAMA**
5	**1**	**E**	**MAMA**	**3**	**D**	**SIMPLE**	**9**	**B**	**MAMA**	**11**	**C**	**SIMPLE**
6	**2**	**A**	**SIMPLE**	**4**	**D**	**MAMA**	**10**	**C**	**SIMPLE**	**12**	**E**	**MAMA**
7	**1**	**D**	**MAMA**	**3**	**C**	**SIMPLE**	**9**	**A**	**MAMA**	**11**	**B**	**SIMPLE**
8	**2**	**C**	**SIMPLE**	**4**	**A**	**MAMA**	**10**	**E**	**SIMPLE**	**12**	**B**	**MAMA**
9	**1**	**C**	**MAMA**	**3**	**B**	**SIMPLE**	**9**	**E**	**MAMA**	**11**	**A**	**SIMPLE**
10	**2**	**E**	**SIMPLE**	**4**	**C**	**MAMA**	**10**	**B**	**SIMPLE**	**12**	**D**	**MAMA**
	Block 3			Block 4			Block 7			Block 8		
1	5	A	SIMPLE	7	C	MAMA	13	D	SIMPLE	15	E	MAMA
2	6	C	MAMA	8	A	SIMPLE	14	E	MAMA	16	B	SIMPLE
3	5	B	SIMPLE	7	D	MAMA	13	E	SIMPLE	15	A	MAMA
4	6	A	MAMA	8	D	SIMPLE	14	C	MAMA	16	E	SIMPLE
5	5	E	SIMPLE	7	B	MAMA	13	C	SIMPLE	15	D	MAMA
6	6	D	MAMA	8	B	SIMPLE	14	A	MAMA	16	C	SIMPLE
7	5	C	SIMPLE	7	E	MAMA	13	A	SIMPLE	15	B	MAMA
8	6	E	MAMA	8	C	SIMPLE	14	B	MAMA	16	D	SIMPLE
9	5	D	SIMPLE	7	A	MAMA	13	B	SIMPLE	15	C	MAMA
10	6	B	MAMA	8	E	SIMPLE	14	D	MAMA	16	A	SIMPLE

A mid-term review of the results, when 40 of the planned 80 tests were completed (the top half of Table 3 in bold type), showed that the dynamometer testing produced much less discrimination among the fuels than the vehicle testing had. Of special note was the difference in CCD levels between the base fuel E and the high-CCD-forming fuel D. For the vehicles, there was a 118% higher CCD for Fuel D, while for the engines, there was approximately a 25% to 50% difference. (The statistical analyses and data plots are discussed in detail below in Section IV.) It was also evident that the results to-date for both the Neon and GM engines were similar. The CCD Panel thus decided to focus further work on only one of the engines for continued testing. The budget for the remaining tests with the other engine could then be spent more profitably by concentrating on improving the discrimination with the selected engine. The smaller Neon engine could be tested more economically than the GM engine, and the CCD Panel therefore selected the Neon engine for concentrated testing. Testing on the GM engine was thus terminated at the midway point.

The vehicles showed 118 percent difference between the high-CCD-forming fuel D and the base fuel E ((D-E)/E). In contrast, the various dynamometer cycles showed approximately 25 to 50 percent differences between Fuels D and E. Because none of the modifications to the dynamometer test cycles accomplished the objective of matching the degree of CCD discrimination as seen in the vehicle tests, the Milder-10 cycle was selected as the best combination of ease of dynamometer operation and discrimination among the fuels. The Milder-10 cycle utilizes five steady-state conditions, a maximum of 70 mph (with the 55-mph segments removed), and linear ten-second acceleration ramps.

IV. DISCUSSION OF RESULTS AND ANALYSES

A. Description of Deposit Analysis

The combustion chamber deposit weight and thickness data and the intake valve data were analyzed using standard linear modeling methods with SAS™ statistical software. The significance of any comparison is based on the residual error from the most appropriate model, which takes into account the known test variables, such as fuel vehicle, cycle, test stand, etc. The factors in the models varied for the different data sets and are described below. With the models accounting for the known test variable, the residual error (standard deviation) is then assumed to be due primarily to test repeatability as measured by replicate tests. As always in such analyses, the residual that goes into the error can also be due to factors that were not included in the models, especially interactions, and various forms of test variability.

1.) For the vehicle road data, within each vehicle type (Chevrolet Silverado or Dodge Neon), the model was Deposit = f(fuel, vehicle) + error, where fuel was A, B, D, D, or E and vehicle was 1, 2, 3, or 4. (Four examples of each vehicle type were tested.)

2.) For the analysis of the first half of the planned initial dynamometer study, within each engine type (Chevrolet Silverado or Dodge Neon), the model was Deposit = f(stand, cycle, fuel) + error, where stand was 2 or 3 (two dynamometer stand were used for each engine type), cycle was MAMA or Simple, and fuel was A, B, C, D, or E.

3.) For the MAMA cycle with soaks, the model was Deposits = f(block, fuel) + error, where block was 3 or 4 and fuel was A, B, B, C, D, or E.

4.) For Table 7 (see below), the model for the vehi9cle data was as given in 1. above. For the MAMA and Milder-10 cycles, within each cycle the model was Deposit = f(fuel) + error, where fuel was A, B, C, D, or E.

5.) For Table 9 (see below), the models for the MAMA and Simple cycles were as given in 2. above. For the MAMA with soaks, the model was as given in 3. above. For the Milder-10 cycle, the model was as given in 4. above.

The following analysis was done when the first half of the dynamometer test matrix was completed. This consisted of 20 tests running the MAMA Dynamometer Cycle and 20 tests on the Simple Dynamometer Cycle with four tests per fuel/additive combination. This is one half of the planned test matrix. CCD total weight, CCD piston top weight, CCD cylinder head weight, CCD average thickness, IVD weight, and Intake Valve Tulip Ratings were analyzed by engine and fuel. Each engine type was tested on two dynamometer stands. However, interaction among stand, fuel, and cycle could not be evaluated because only half of the planned experiments were completed. Such interactions, if they exist, would then be expected to inflate variability, making main effects harder to detect or, in the worst case, confound main effects.

B. <u>Analysis for Fuel Effects in the GM Silverado Engine on the MAMA and Simple Dynamometer Cycles</u>

The analyses of CCD Total Weight, CCD Piston Top Weight, CCD Cylinder Head Weight, CCD Average Thickness, IVD Weight, Intake Valve Deposit Weight and Intake Valve Tulip Ratings are shown in Figures 12 - 17. The alpha level for the error bars in these figures is 0.05 (95% "confidence level").

CCD Total Weight, Piston Top Weight, and Cylinder head Weight all show a consistent pattern of higher deposit weights for Fuel D (the high-CCD reference additive). Differences among the other fuels (unadditized base fuel and the three commercial detergent packages) were not statistically significant (alpha = 0.05). In contrast, in the GM Silverado vehicle tests, the unadditized base fuel was significantly different from the three commercial detergent additive packages.

No significant fuel differences were found for CCD Average Thickness.

As expected, Fuel E, the base fuel without detergent additive, had significantly higher IVD weight. Of the additized fuels, Fuel C had higher IVD weight than the Fuels A, B, and D, but was not significantly different from this group, with alpha = 0.05.

Fuel E had significantly lower CRC Visual Valve Tulip Ratings (scale of 1 to 10, where 10 is clean) than Fuels A, B, and D. Fuel C was lower than Fuels A, B, and D. This difference was statistically significant for Fuels A and B

C. Analysis for Fuel Effects in the DC Neon Engine on the MAMA and Simple Dynamometer Cycles

The analyses of CCD Total Weight, CCD Piston Top Weight, CCD Cylinder Head Weight, CCD Average Thickness, Intake Valve Deposit Weight, and Intake Valve Tulip Ratings are shown in Figures 18-23. The alpha level for the error bars in these figures is 0.05 (95% "confidence level").

Fuels A and D had significantly higher CCD Total Weight than Fuels B and E. **F**or the DC Dodge Neon vehicles and Fuel E deposit weights were significantly lower than for the other fuels. Fuel D produced significantly higher deposits weights than those from Fuels C, B, and E, but are not significantly different than those from Fuel A.

Fuel A had significantly higher CCD Piston Weight than Fuel E. Fuel A had significantly higher CCD Cylinder Head Weight than Fuel B.

CCD average thickness was highly variable with no significant fuel differences.

Fuel E, the base fuel without detergent additive, had significantly higher IVD weight than Fuels A, B, and D. Fuel C was higher, but not significantly, than Fuels A, B, and D.

As with the Chevrolet engine, Fuel E had significantly lower valve tulip ratings. Fuel C was lower than Fuels A, B, and D. This was significant for Fuels A and B.

D. Comparisons Between the Engine Dynamometer on the MAMA and Simple Cycles and the Vehicle Deposits

The road and dynamometer data for CCD Total Weight and Average Thickness are compared in Figures 24 and 25 for the GM Silverado. Base Fuel E without detergent additive had higher CCD weight and thickness in the engines than in the vehicles. The engine dynamometer average CCD Total Weight for Fuels A, B, C, and D were nearly equal to the vehicle averages.

The road and dynamometer data for CCD Total Weight and Average Thickness are compared in Figures 26 and 27 for the DC Neon. Fuels A and E had higher CCD Total Weight in the engines than in the vehicles. Section V below contains additional analysis of the MAMA Cycle compared to the Milder-10 Cycle and to the DC Neon Vehicle.

E. Influential Observations

In all of these analyses, only one observation was flagged as being a possible "outlier". The CCD Cylinder Head Weight for the DC Neon engine on Dynamometer Stand 2 running the MAMA cycle on Fuel A was below its fitted value. This datum was not eliminated from the analyses. This stand running the MAMA cycle is quite similar to the vehicle average for Fuels A through D for CCD Total Weight, but is very different from the vehicle average for CCD Average Thickness.

F. MAMA Cycle with Soaks

The Dodge Neon Engine CCD Total Weight for the MAMA Cycle with the eight-hour soaks is shown in Figure 28 compared to the MAMA and Simple Cycle results. This data set contains twelve tests, giving three results for each of the fuels A, C, D, and E. Inspection of Figure 28 indicates that the addition of the eight-hour soaks did not improve discrimination among the fuels. In particular, the deposit levels for Fuel E were similar for this modified dynamometer cycle as compared with the previous two cycles. The absence of a discernable effect of engine-off soaks is consistent with the findings of the earlier CCD parametric study[4].

G. Chemical Analysis of Deposits and Examination of Photographs

Additional steps were taken in an effort to understand the apparent differences in the degree of CCD discrimination between the vehicle and dynamometer results: chemical analysis of the deposits and examination of the photographs of the piston tops and cylinder head deposits.

Selected deposit samples from the DC Neon vehicles and engines were analyzed for carbon, hydrogen, nitrogen using ASTM D 5291 and for various metals using ICP (EPA 6010) for Fuels D and E. Two vehicle samples were also selected to be as close as possible to the average CCD Total Weight. One CCD sample for each fuel was selected for five of the dynamometer test cycles. Piston top and cylinder head deposits were combined in equal proportions and thoroughly mixed prior to analysis. These analyses, done at SwRI, are tabulated in Table 4. Some differences in metal content between some of the engine tests were observed, but these could not be related to differences seen in CCD levels between the engine and vehicle tests.

Table 4

Composition Analysis of CRC CCD Samples

	DN1 99015	DN2 99016	DN1 99019	DN4 99022	DC2 04	DC2 08	DC2 11	DC2 13	DC2 19	DC2 20	DC2 21A	DC2 22	DC2 24	DC2 25
TEST FUEL	**E**	**D**	**D**	**E**	**D**	**E**	**D**	**E**	**E**	**D**	**E**	**D**	**D**	**E**
					Simple	**Simple**	**MAMA w/Soak**	**MAMA w/Soak**	**Milder**	**Milder**	**MLD-10**	**MLD-10**	**SIM-15**	**SIM-15**
ASTM D5291 (mass%)														
C	49.50	52.72	52.32	50.56	53.67	54.96	45.90	44.34	55.60	58.26	53.77	52.07	60.54	56.84
H	3.03	3.42	3.39	2.86	3.45	2.87	2.87	2.59	3.35	3.57	2.77	3.09	3.77	2.94
N	3.21	3.00	3.15	3.57	3.38	2.50	2.87	2.59	3.35	3.57	3.18	3.09	3.77	2.94
EPA 6010 (ppm)														
Ag	<17	<12	<12	<10	19	<14	<11	<10	<14	<10	<11	<12	<11	<13
Al	11848	6396	1945	15336	3523	2241	2468	2880	469	945	1926	3596	1475	1716
B	140	143	135	144	109	173	352	257	203	126	89	116	137	104
Ba	<17	<12	33	57	<13	<14	14	<10	<14	<10	<11	<12	<11	<13
Cd	<17	342	115	<10	82	<14	86	<10	<14	69	<11	96	48	<13
Ca	16997	11124	10877	11349	10598	12626	29126	37325	21161	8332	10954	1046	6379	9507
Cr	323	284	390	217	62	32	60	23	84	225	26	113	108	26
Cu	3317	8207	8422	3399	9070	2463	2324	548	1011	3528	2258	3016	2670	2376
Fe	3330	3451	4481	2974	1532	1748	1468	1018	689	2058	801	1856	1886	1980
K	<17	<12	<12	<10	<13	<137	<106	<103	<142	<98	<107	<116	<111	<132
Pb	190	555	2277	575	374	456	117	493	787	794	1743	1740	1063	1716
Mg	12109	6929	7501	7903	7764	8258	20924	26420	14910	5880	7778	12296	4432	6864
Mn	61	117	121	84	47	87	51	33	22	31	22	46	26	26
Ni	451	556	360	1793	200	156	170	171	184	216	186	255	152	119
Na	3910	2611	2936	2584	2508	2370	6290	8065	4970	1862	2279	4060	1082	2244
P	13940	12029	10670	9831	10772	9398	20416	26605	14342	5586	8890	12296	7436	7524
Sb	<170	<116	<116	<103	<128	<137	<106	<103	<14	<10	<107	<12	<111	<13
Si	797	1071	687	574	819	671	610	936	814	867	734	678	609	600
Sn	<170	2997	1104	5086	<128	<137	<106	<103	<142	<98	<107	<116	<111	<132
Sr	30	21	20	20	21	24	50	58	38	22	20	35	12	<13
Ti	20	15	13	24	<13	<14	<11	<10	<14	<10	<11	<12	<11	<13
V	<17	<12	<12	<10	<13	<14	<11	<10	<14	<10	<11	<12	<11	<13
Zn	19210	16020	13456	13060	22720	13245	31493	35216	20732	10486	11267	19024	8834	9768
Mo	19	38	37	20	22	<137	<106	<103	<14	<10	<107	<12	<111	<13

Experienced members of the Combustion Chamber Deposit Program Panel examined photographs of the piston tops and cylinder head deposits from both the road and dynamometer work. In particular, these photographs were studied for any signs of gross flaking (distinctive areas without deposits) that might account for the differences between the road and dynamometer test in CCD total weight measurements. No significant differences could be seen, however. The photographic records from both Parts 1 and 2 of this program are on file with the CRC.

H. Fuel Consumption Differences Between the Road and the Dynamometer Cycles

During investigations to resolve the differences between the road and dynamometer deposit results, it was found that there were significant differences in the fuel consumption. In particular, it was found that the MAMA dynamometer cycle consumed 56 percent more fuel per running hour than had been realized on the road. A variety of dynamometer cycles was designed and tested to better match fuel consumption between the vehicle and the engine tests. These data are reported in Table 5. The Milder-10 cycle came the closest to the road fuel consumption.

Table 5

FUEL CONSUMPTION DIFFERENCES BEWEEN THE ROAD AND DYNAMOMETER CYCLES

CYCLE	HOURS	GAL/HR	DELTA
VEHICLE 2.0 LITRE NEON, MAMA ROAD	395	1.39	0%
MAMA ON DYNO	300	2.17	56%
MAMA WITH LINEAR RAMPS	25.4	1.45	4%
SIMPLE - MAMA STAGE TARGETS, FEWER RAMPS	300	1.67	20%
MILDER - ONE 55 MPH MAX STAGE	300	0.93	-33%
MILDER + ONE 70 MPH STAGE	23.9	1.18	-15%
MILDER + ONE 70 AND ONE 60 MPH STAGES	23.6	1.28	-8%
MILDER + TWO 70 MPH STAGES	23.5	1.57	13%
SIMPLE, LINEAR, 15 SEC RAMPS	24	1.26	-9%
MILDER-10 [70, 60, 10 SEC RAMPS]	300	1.38	-1%
SIM-15 [LINEAR, 15 SEC RAMPS]	300	1.27	-9%

I. Milder and Simple-15 Cycles

The next cycle to be investigated for combustion chamber deposits was the "Milder" cycle. This is defined in Table 2 and shown graphically in Figure 10 and, as can be seen in Table 5 above, had fuel consumption 33 % (0.93 gal/hr) less than the road MAMA cycle. Duplicate tests of only Fuels D and E were done. CCD Total Weight was found to increase with the Milder cycle to 10.609 g for Fuel D and to 8.632 g for Fuel E, compared to 8.703 g and 5.819 g, respectively, for the MAMA dynamometer cycle. This cycle was not studied further, as Fuel D results were not sufficiently different from Fuel E results.

The “Simple-15” cycle (Table 2 and Figure 9) had fuel consumption 9 % less than the road MAMA cycle. Single tests with Fuels D and E were done to assess the impact of these cycle changes. CCD Total Weight was 10.030 g for Fuel D and 7.462 g for Fuel E. This cycle was not studied further, as Fuel D results were not sufficiently different from Fuel E results. Other details for this and the Milder cycle are tabulated in Appendix E.

J. <u>Milder-10 Cycle</u>

The Milder-10 (MLD-10) dynamometer cycle is defined in Table 2 and shown graphically in Figure 11. This cycle was found to match the road testing in fuel consumption within 1 % (see Table 5). It was thought that matching fuel consumption would bring the dynamometer results into alignment with the road testing. Single tests were run with Fuels A, B, and C, four tests with Fuel D (the high CCD reference fuel), and three tests with Fuel E (the unadditized base fuel). The CCD Total Weight is shown in Figure 29 and the Average CCD Thickness is shown in Figure 30 and these are compared to the vehicle data. Note that the error bars ($\alpha = 0.05$, "95% confidence level") included for the vehicle data apply only to the vehicle data and are intended to help in comparing across the fuel set for the vehicles. They do not apply to comparisons between the dynamometer and vehicle experiments. Section V below contains additional analysis of the Milder-10 Cycle compared to the MAMA Cycle and to the DC Neon Vehicle.

V. STATISTICAL DISCUSSION OF DEPOSIT PARAMETERS FOR THE MAMA AND MILDER-10 DYNAMOMETER CYCLES

The MAMA and Milder-10 Dynamometer Cycles appeared to be the most promising of the six cycles tested. This prompted further statistical analysis of these two compared to the Neon vehicle work. Table 6 contains the average CCD Total Weight and the average CCD Average Thickness for the Neon vehicle and the MAMA and Milder-10 dynamometer cycles. Also included are the average IVD Boroscope Ratings for the Neon vehicle and the average IVD weights for the two dynamometer cycles. Note that each test type contains a different number of tests per fuel-additive combination. All are arranged in rank order. The MAMA Dynamometer Cycle duplicates the rank order seen in the Neon Vehicle results in all three categories of deposits. The Milder-10 Dynamometer Cycle results have a different rank order than the vehicle results but the ordering is consistent across the three deposit categories. For both cycles the Base Fuel E produced lowest CCD Total Weight and Thickness and the high CCD reference, D, produced the highest. The three commercial additive packages in Fuels A, B, and C produced intermediate levels.

Figure 31 summarizes the Dodge Neon CCD Total Weight data for the MAMA and Milder-10 dynamometer cycles compared to the vehicle results using averages for each fuel for each type of experiment. Again, as given in Table 6, note that these averages do not represent the same number of data points in all cases and should be interpreted with some care.

Table 7 summarizes the statistical significance of the deposit levels differences among the test fuels for CCD Total Weight, CCD Average Thickness, and IVD Boroscope Ratings/Weights for the Dodge Neon. This is similar to Table 1 which summarizes the vehicle work for the Chevrolet Silverado and Dodge Neon. For each test cycle the fuel-additive combinations are given in rank order: heaviest to lightest for CCD Total Weight, thickest to thinnest for CCD Average Thickness, and highest rating (lowest valve deposits) to lowest rating (heaviest deposits) for IVD Ratings and IVD Weights. The left side is for the vehicle test program (identical to the Neon data in Table 1). This column is for a Type I error rate, α, of 0.05. The other columns of data compare the MAMA and Milder-10 dynamometer cycles for three levels of alpha: 0.05, 0.10, and 0.20. These are sometimes called the 95%, 90% and 80% "Confidence Levels". The vertical bars ("|") indicate those that are not significantly different at the specified alpha level. Pairs of fuels that do not share a "|" in the same column were significantly different from each other.

For the MAMA Dynamometer Cycle at $\alpha = 0.05$ only the IVD Weights show some difference. Fuel-additive combinations D, A, and B are statistically different than Fuels C and E at this level. When alpha is increased to 0.10, some separation is seen in the CCD Weights with Fuels D and A being statistically different than Fuel E. No separation is seen in the CCD Average Thicknesses. The IVD Ratings show statistical differences between the grouping of Fuels D, A, and B versus the pair of Fuels C and E. When alpha is increased to 0.20, the MAMA Cycle shows that Fuels D and A produced heavier deposits than Fuels B and E but are not significantly different than Fuel C. For CCD Average Thickness, Fuel D was significantly higher than Fuels B and E.

For the Milder-10 Dynamometer Cycle at $\alpha = 0.05$ only the IVD Weights show some difference. Fuel-additive combinations D, A, and B are statistically different than C and E at this alpha level. When alpha is increased to 0.10, some separation is seen in the CCD Total Weights with Fuels D being statistically different than Fuel E. The CCD Thicknesses do not separate at all. Fuel D gave significantly lighter IVD Weights than the grouping of Fuels A, C, and D and Fuel E gave the heaviest deposits. Increasing alpha to 0.20 does not change the resolution or pattern for the Milder-10 Cycle.

Table 6

SUMMARY OF AVERAGE CCD WEIGHTS, AVERAGE CCD THICKNESSES, AND AVERAGE IVD DEPOSITS FOR THE NEON VEHICLE AND THE MAMA AND MILDER-10 DYNAMOMETER CYCLES

Neon Vehicle		MAMA Cycle		MILDER-10 Cycle		
#	of Test per Fuel-Additive = 4	#	of Test per Fuel-Additive = 2			
FUEL	CCD Total Weight, g	FUEL	CCD Total Weight, g	FUEL	CCD Total Weight, g	# of Test per Fuel-Additive
D	8.15	D	8.70	D	8.77	4
A	6.8	A	8.46	C	7.96	1
C	6.6	C	7.16	A	7.64	1
B	5.85	B	6.24	B	7.64	1
E	3.73	E	5.82	E	7.15	3
FUEL	CCD Average Thickness, mil	FUEL	CCD Average Thickness, mil	FUEL	CCD Average Thickness, mil	# of Test per Fuel-Additive
D	6.87	D	6.80	D	7.27	4
A	6.46	A	5.00	C	7.24	1
C	5.50	C	4.95	A	6.50	1
B	4.72	B	4.71	B	5.33	1
E	3.62	E	4.64	E	5.10	3
FUEL	IVD Ratings	FUEL	IVD, mg	FUEL	IVD, mg	# of Test per Fuel-Additive
D	9.52	D	2.40	D	6.35	4
A	9.4	A	6.99	A	202.10	1
C	9.37	C	7.89	C	251.90	1
B	7.08	B	520.31	B	353.80	1
E	6.73	E	526.76	E	704.27	3

Table 7

RANKINGS AND SIGNIFICANCE* OF THE DEPOSIT PARAMETERS FOR THE NEON VEHICLE AND THE MAMA AND MILDER-10 DYNAMOMETER CYCLES

<table>
<tr><th></th><th>Vehicle α=0.05</th><th>MAMA α=0.05</th><th>MILDER-10 α=0.05</th><th>MAMA α=0.10</th><th>MILDER-10 α=0.10</th><th>MAMA α=0.20</th><th>MILDER-10 α=0.20</th><th></th></tr>
<tr><td rowspan="5">CCD Weight</td><td>| D</td><td>| D</td><td>| D</td><td>| D</td><td>| D</td><td>| D</td><td>| D</td><td>Heaviest</td></tr>
<tr><td>| | A</td><td>| A</td><td>| C</td><td>| A</td><td>| | C</td><td>| A</td><td>| | C</td><td></td></tr>
<tr><td>| C</td><td>| C</td><td>| A</td><td>| | C</td><td>| | A</td><td>| | C</td><td>| | A</td><td></td></tr>
<tr><td>| B</td><td>| B</td><td>| B</td><td>| | B</td><td>| | B</td><td>| B</td><td>| | B</td><td></td></tr>
<tr><td>E</td><td>| E</td><td>| E</td><td>| E</td><td>| E</td><td>| E</td><td>| E</td><td>Lightest</td></tr>
<tr><td rowspan="5">CCD Thickness</td><td>| D</td><td>| D</td><td>| D</td><td>| D</td><td>| D</td><td>| D</td><td>| D</td><td>Thickest</td></tr>
<tr><td>| | A</td><td>| A</td><td>| C</td><td>| A</td><td>| C</td><td>| | A</td><td>| C</td><td></td></tr>
<tr><td>| | C</td><td>| C</td><td>| A</td><td>| C</td><td>| A</td><td>| | C</td><td>| A</td><td></td></tr>
<tr><td>| | B</td><td>| B</td><td>| B</td><td>| B</td><td>| B</td><td>| B</td><td>| B</td><td></td></tr>
<tr><td>| E</td><td>| E</td><td>| E</td><td>| E</td><td>| E</td><td>| E</td><td>| E</td><td>Thinnest</td></tr>
<tr><td rowspan="5">IVD Rating/Wt</td><td>| D</td><td>| D</td><td>| D</td><td>| D</td><td>D</td><td>| D</td><td>D</td><td>Lowest Deposits</td></tr>
<tr><td>| A</td><td>| A</td><td>| | A</td><td>| A</td><td>| A</td><td>| A</td><td>| A</td><td></td></tr>
<tr><td>| B</td><td>| B</td><td>| C</td><td>| B</td><td>| C</td><td>| B</td><td>| C</td><td></td></tr>
<tr><td>| C</td><td>| C</td><td>| B</td><td>| C</td><td>| B</td><td>| C</td><td>| B</td><td>Heaviest</td></tr>
<tr><td>| E</td><td>| E</td><td>E</td><td>| E</td><td>E</td><td>| E</td><td>E</td><td>Deposits</td></tr>
</table>

*Pairs of fuels that do not share a '|' in the same column were significantly different from each other. See Table 1 and page 6 for examples.

VI. RECOMMENDATION OF THE DODGE NEON ENGINE AND THE MILDER-10 DYNAMOMETER CYCLE FOR FUTURE DEVELOPMENT

The Dodge Neon engine and the Chevrolet Silverado engine tests gave comparable results for the MAMA and Simple cycles. As the Neon engine is less expensive to operate, it was therefore decided to continue future CCD investigations only with this engine.

Of the six dynamometer cycles evaluated, the one designated as the "MAMA" cycle provided slightly better ability to differentiate test fuels based on their total CCD weight. The CCD ranking pattern of the MAMA cycle was similar to the vehicle data. However, the Milder-10 cycle is recommended for future use as a research tool for the evaluation of combustion chamber deposits in spark-ignition engines for the following reasons. This cycle matches the fuel consumption seen in the Dodge Neon vehicle testing on the road. It is judged that this cycle will be easier to program and run repeatably than the much more complex and difficult MAMA dynamometer cycle. The Milder-10 cycle resulted in the same general CCD pattern as the other cycles, although the rank order of the deposits was slightly different. The base fuel, E, resulted in the lowest CCD Total Weight. The high CCD reference fuel, D, gave the highest deposits with the commercial packages in Fuels A, B, and C giving intermediate levels. This is the same pattern as with the vehicle studies. The separation among the fuels is, however, not as large as in the vehicles. Statistical analysis with the limited data available shows that this engine/cycle/test duration can resolve the differences between the unadditized base Fuel E and the high CCD reference Fuel D, as summarized in Table 8. As shown in Table 9, this combination of engine and cycle has lower residual error and coefficient of variation than the other engines and cycles tested. The concern remains, however, that the CCD difference between Fuels D and E is smaller for the Milder-10 cycle while the precision appears to be better. As shown in Table 10, with this precision for the Milder-10 cycle, 14 tests are required to distinguish between two fuels which differ in CCD Total Weight by 10%. Four tests are required to distinguish between two fuels which differ by 20%. This is based on a limited data base and may not be borne out by future testing, particularly including more engine stands.

Table 8

STATISTICAL RESOLUTION FOR THE NEON ENGINE AND MILDER-10 CYCLE

Fuels Significantly Different at:	MILDER-10 Cycle
α = 0.05 "95% Confidence Level"	None
α = 0.10 "90% Confidence Level"	D & E
α = 0.20 "80% Confidence Level"	D & E

Table 9

RESIDUAL ERROR AND COEFFICIENT OF VARIATION OF MILDER-10 CYCLE

	Residual Error (1)	Coefficient of Variation (2)
Silverado Engine: MAMA and Simple Cycles	2.22	12%
Neon Engine: MAMA and Simple Cycles	0.76	10%
Neon Engine: MAMA with Soaks	1.29	18%
Neon Engine: MLD-10	0.6	8%

(1) Residual Error is an estimate of standard deviation after accounting for factors in the model (in this case the only factor was fuel).
(2) Coefficient of Variation = (Residual Error/Average) × 100.

Table 10

REQUIRED TESTS FOR NEON ENGINE AND THE MILDER-10 CYCLE

Difference Between 2 Fuels in CCD Total Weight	Number of Tests Required
10%	14
20%	4

VII. "BENCH TESTS" FOR EVALUATING CCD POTENTIAL

ASTM D 381 Gum and a thermal gravimetric analysis (TGA) of the unwashed gums developed by Ford have been proposed as laboratory bench tests to evaluate the CCD-forming potential of fuels and/or fuel additive combinations. These techniques were evaluated during this program against the vehicle CCD determinations.

A. ASTM D 381 GUM

Unwashed gum residue from the five gasolines were prepared per ASTM D 381 Standard Test Method for Gum Content in Fuels by Jet Evaporation. The unwashed gums by themselves did not give useful correlations of CCD potential. As shown in Figure 32, the linear regressions have low R^2.

B. FORD TGA TEST METHOD

The Ford TGA test method (FLTM BZ-154-01) is a bench method that was developed to evaluate thermal decomposition of unwashed gum residues from gasolines containing detergent additives using thermal gravimetric analysis (TGA).

The unwashed gum of the gasoline sample is prepared per ASTM D 381 Standard Test Method for Gum Content in Fuels by Jet Evaporation. A sample size of 10-15 mg is then transferred, using methylene chloride as a solvent, to the TGA pan. The sample is then heated at a controlled rate of 5°C/minute from 150°C to 500°C in an air environment at a flow rate of 55 ml/min. The thermal decomposition of the sample is reported as a function of weight change versus temperature. The TGA data for each test are reported as percent weight at temperatures of 250°C, 300°C, 350°C, 400°C, and 450°C.

Additional details on sample preparation can be found in Appendix F, and the full test method can be obtained from Ford Motor Company.

C. CORRELATION OF THE FORD TGA METHOD

Figure 33 shows TGA residue versus temperature charts for the five fuel/additive combinations tested in this program. Figure 34 shows the TGA residue traces for the five gasoline unwashed gums. (The percent residue on the left axis is associated with the curves beginning at 100 percent. The derivative, weight percent/minute, on the right axis is associated with the curves beginning at 0 percent.) Fuel E, the base fuel without detergent additive, is clearly distinguishable from the four additized fuels. A number of linear regression analyses were done by Ford Motor Company using the data as shown in Table 10. Note that in all cases the average vehicle CCD Total Weight was used. It has been noted that the washed gum level (6.8 mg/100 mL) for the unadditized base fuel is unusually high for an unadditized fuel. However, this value is consistent with the base fuel inspection data during the period of the work at PEAR (see Appendix D). Figure 35 shows the regressions for the Chevrolet Silverado average CCD deposits, Figure 36 for the Dodge Neon, and Figure 37 for the combined average of the two vehicle types. The TGA residue at each of four temperatures, 300°C, 350°C, 400°C, and 450°C, is multiplied by the Unwashed Gum and regressed versus the CCD Total Weight. The best fit of the CCD data for a single variable using all fuels was found for Unwashed Gum multiplied by TGA Residue at 350°C. The three regressions for the Chevrolet Silverado, the Dodge Neon, and the combined average of the two vehicle types are summarized in Figure 38 for all of the fuels. If the base fuel is excluded from the analysis (Figure 39), then Unwashed Gum × TGA Residue at 450°C provides the best fit (compare the R^2 values between Figures 38 and 39). The analyses also show that the data fit is significantly improved when a combination of Unwashed Gum × TGA Residue at 350°C and Unwashed Gum × TGA Residue at 400°C are fitted to the CCD data for all fuels (see Table 11). The three 2-variable regressions for the Chevrolet Silverado, the Dodge Neon, and the combined average of the two vehicle types are shown in Figures 40, 41, and 42 respectively.

A second analysis of the data was carried out using the full vehicle CCD Total Weight set without first averaging the individual vehicle CCD data. This introduces the variability in the Y-axis only. Figure 43 shows the linear regressions for the CCD for each vehicle type versus Unwashed Gum × TGA Residue at 350°C for comparison to Figure 38. Figure 44 shows the regression against Unwashed Gum × TGA Residue at 450°C for only the four additized fuels. This can be compared to Figure 39. In both cases the regressions without first averaging the vehicle CCD data show lower R^2 values than do the regressions using the average CCD data.

Within this program no attempt was made to evaluate the variability in the TGA residual or Unwashed Gum results, introducing variability in the X-axis. Only single measurements were made for each fuel. The repeatability given in ASTM D 381 for Unwashed Gum range from about 9 % for the high CCD fuel (Fuel D) to about 31 % for the unadditized base fuel (Fuel E). Error in the TGA residue determinations would compound the variability in the product.

The analyses with and without the variability in the CCD Total Weight lead to somewhat different conclusions about the immediate utility of the gum/TGA bench test. Concern has also been raised about the best-fit correlation not including base fuel. This would result in difficulties with base fuels and lightly additized fuels. Nevertheless, this bench test has some potential for further development but additional work needed to confirm the correlation is recommended. It is recommended that additional data be added to the data set whenever possible and that the variability of the Unwashed Gum × TGA parameters be investigated.

Table 11 (Page 1 of 2)

LINEAR REGRESSION ANALYSES OF AVERAGE VEHICLE CCD VERSUS TGA AND UNWASHED GUM

					TGA, % Remaining				Unwashed Gum x TGA % remaining			
Fuel	**Ave. CCD**	**GM ccd**	**Dodge ccd**	**Unw Gum**	**300C**	**350C**	**400C**	**450C**	**Gum*T300C**	**Gum*T350C**	**Gum*T400C**	**Gum*T450C**
A	12.58	18.4	6.8	22.4	81.0	47.4	23.2	13.4	18.14	10.62	5.20	3.00
B	10.68	15.5	5.9	32.0	81.6	27.3	13.2	7.0	26.11	8.74	4.22	2.24
C	11.08	15.6	6.6	15.2	85.8	**56.7**	26.1	15.9	13.04	8.62	3.97	2.42
D	15.68	23.2	8.1	55.8	63.0	35.6	19.3	6.7	35.15	19.86	10.77	3.74
E	6.73	9.7	3.7	6.8	87.9	81.8	72.0	59.7	5.98	5.56	4.90	4.06

Linear Regression Results for All Fuels

1-Variable

The regression equation is
Ave. CCD = 5.47 + 0.550 Gum*T350C

Predictor	Coef	SE Coef	T	P
Constant	5.475	1.559	3.51	0.039
Gum*T350	0.5501	0.1328	4.14	0.026

S = 1.446 R-Sq = 85.1% R-Sq(adj) = 80.2%

2-Variable

The regression equation is
Ave. CCD = 6.25 + 1.11 Gum*T350C - 1.17 Gum*T400C

Predictor	Coef	SE Coef	T	P
Constant	6.2548	0.5640	11.09	0.008
Gum*T350	1.1150	0.1265	8.82	0.013
Gum*T400	-1.1722	0.2445	-4.79	0.041

S = 0.5009 R-Sq = 98.8% R-Sq(adj) = 97.6%

Table 11 (Page 2 of 2)

The regression equation is
Dodge ccd = 3.50 + 0.256 Gum*T350C

Predictor	Coef	SE Coef	T	P
Constant	3.498	1.034	3.38	0.043
Gum*T350	0.25563	0.08809	2.9	0.062

S = 0.9589 R-Sq = 73.7% R-Sq(adj) = 65.0%

The regression equation is
Dodge ccd = 4.01 + 0.630 Gum*T350C - 0.776 Gum*T400C

Predictor	Coef	SE Coef	T	P
Constant	4.0147	0.3811	10.53	0.0009
Gum*T350	0.62972	0.08546	7.37	0.018
Gum*T400	-0.7763	0.1652	-4.70	0.042

S = 0.3384 R-Sq = 97.8% R-Sq(adj) = 95.6%

The regression equation is
GM ccd = 7.46 + 0.844 Gum*T350C

Predictor	Coef	SE Coef	T	P
Constant	7.457	2.135	3.49	0.04
Gum*T350	0.8441	0.1819	4.64	0.019

S = 1.980 R-Sq = 87.8% R-Sq(adj) = 83.7%

The regression equation is
GM ccd = 8.50 + 1.60 Gum*T350C - 1.57 Gum*T400C

Predictor	Coef	SE Coef	T	P
Constant	8.499	1.9646	8.81	0.013
Gum*T350	1.5989	0.2163	7.39	0.018
Gum*T400	-1.5662	0.4181	-3.75	0.064

S = 0.8566 R-Sq = 98.5% R-Sq(adj) = 96.9%

VIII. SUMMARY AND CONCLUSIONS

The Dodge Neon engine and the Chevrolet Silverado engine tests gave comparable results for the MAMA and Simple cycles. As the Neon engine is less expensive to operate, it is recommended that this engine be used in future CCD investigations.

Of the six dynamometer cycles evaluated, the one designated as the "MAMA" cycle provided slightly better ability to differentiate test fuels based on their total CCD weight. The CCD ranking pattern of the MAMA cycle was also similar to the vehicle data. However, the considerable improvement in operational and implementation simplicity as well as overall acceptable performance in differentiating fuels based on their CCD formation tendency are the overwhelming reasons that the group is recommending the Milder-10 cycle as a research tool. Additionally, the Milder-10 cycle matches the fuel consumption seen in the Dodge Neon vehicle tested on the road. In general, the vehicle data showed somewhat better discrimination than do the limited dynamometer data, but this could change with additional dynamometer testing.

The Ford TGA bench test shows some potential for predicting combustion chamber deposits, particularly for additized fuels. Applying the test to unadditized fuels is not recommended. More work is required to confirm the correlation. This test has potential for further development beyond what was accomplished in this program. It is recommended that additional data be added to the data set whenever possible and that the variability of the Unwashed Gum × TGA parameters be investigated.

IX. ACKNOWLEDGEMENTS

The CRC Combustion Chamber Deposit Panel wishes to thank PerkinElmer Automotive Research for conducting the engine dynamometer testing, for preparing their summary report, and for sharing data files for the data analysis and preparation of this report. The Panel also wishes to thank the Coordinating Research Council for providing financial support for the preparation of this report. Special mention should be made of DaimlerChrysler and General Motors for supplying the engines, hardware, and assistance to install them. Jim Rutherford of Chevron Oronite Company is to be commended for his conscientious statistical work.

X. REFERENCES

1. Coordinating Research Council, Inc., Combustion Chamber Deposit Research Tool Development: Part 1 – Vehicle Deposits and Emissions, CRC Report No. 630, April 2002.

2. Coordinating Research Council, Inc., Effects of Combustion Chamber Deposits on Vehicle Emissions and Fuel Economy, CRC Report No. 624, April 2000.

3. Coordinating Research Council, Inc., A Field Validation Study to Determine In-Use Combustion Chamber Deposit Levels, CRC Report No. 604, December 1997.

4. Coordinating Research Council, Inc., Combustion Chamber Deposit Test Method Development Parametric Study, CRC Report No. 608, August 1998.

5. Office of the Federal Register, National Archives and Records Administration, Code of Federal Regulations, 40, Part 86, Appendix IV.

LIST OF TABLES

LIST OF FIGURES

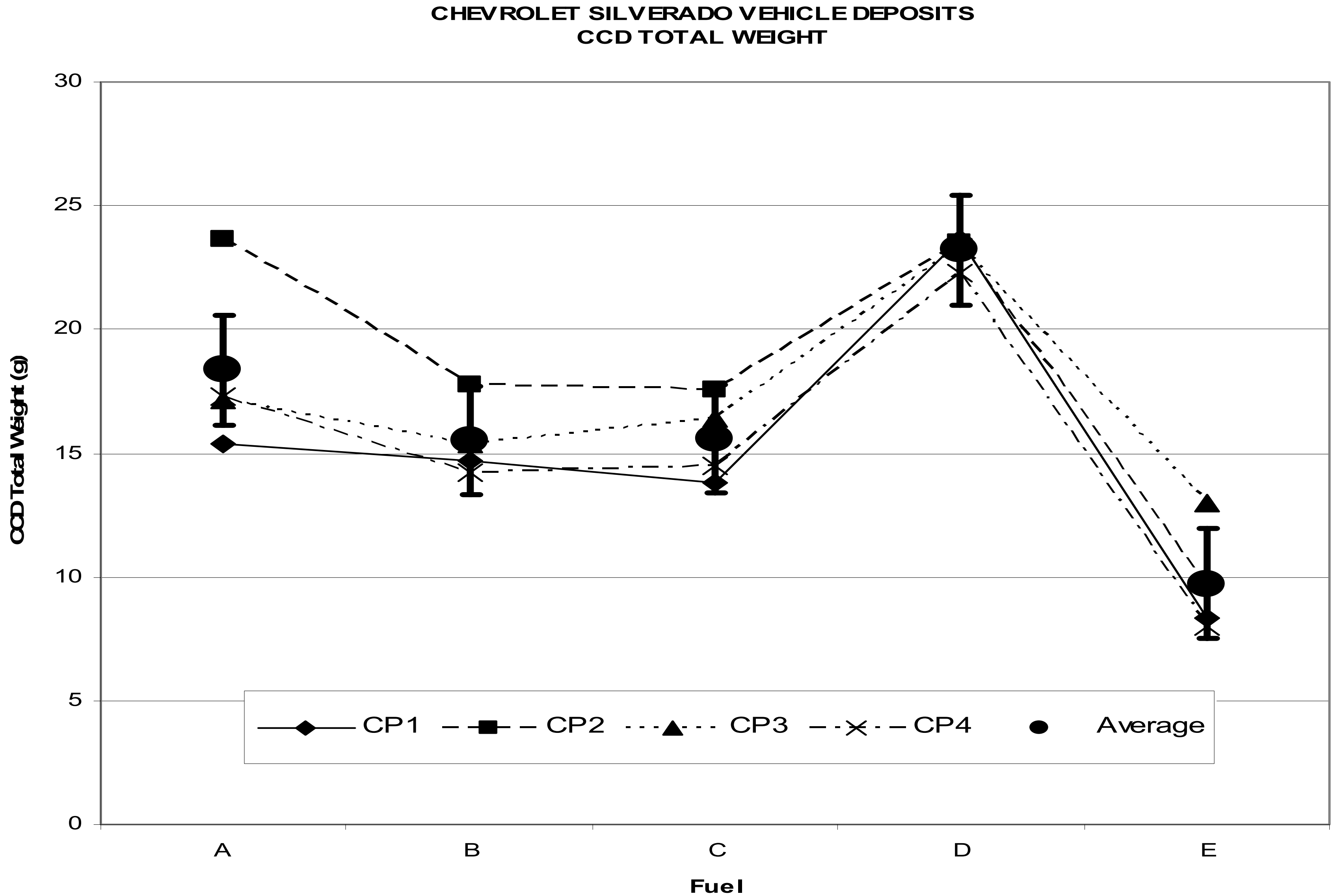


Figure 1 (Figure 5 from Part 1 Report)

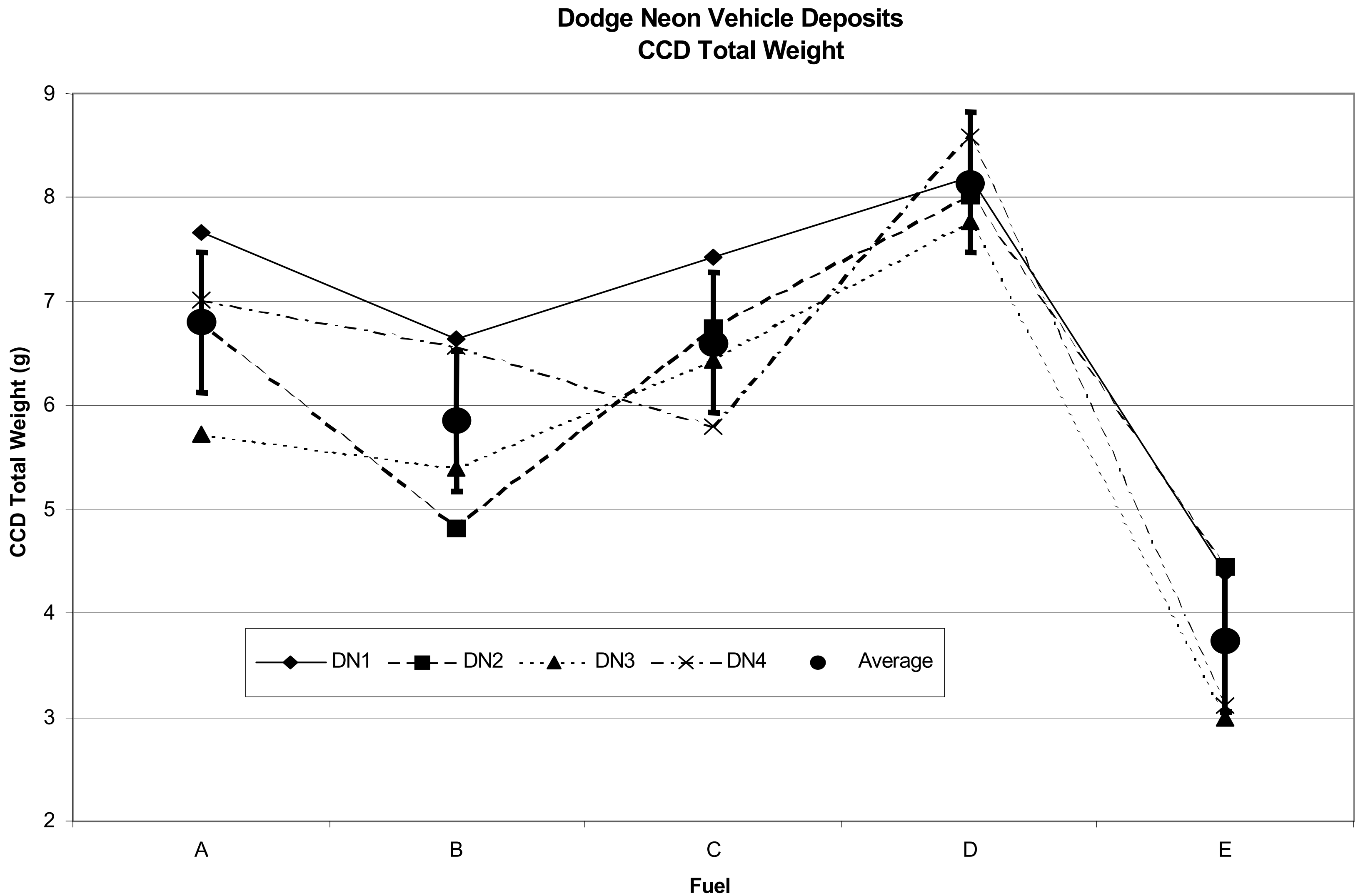


Figure 2 (Figure 11 from Part 1 Report)

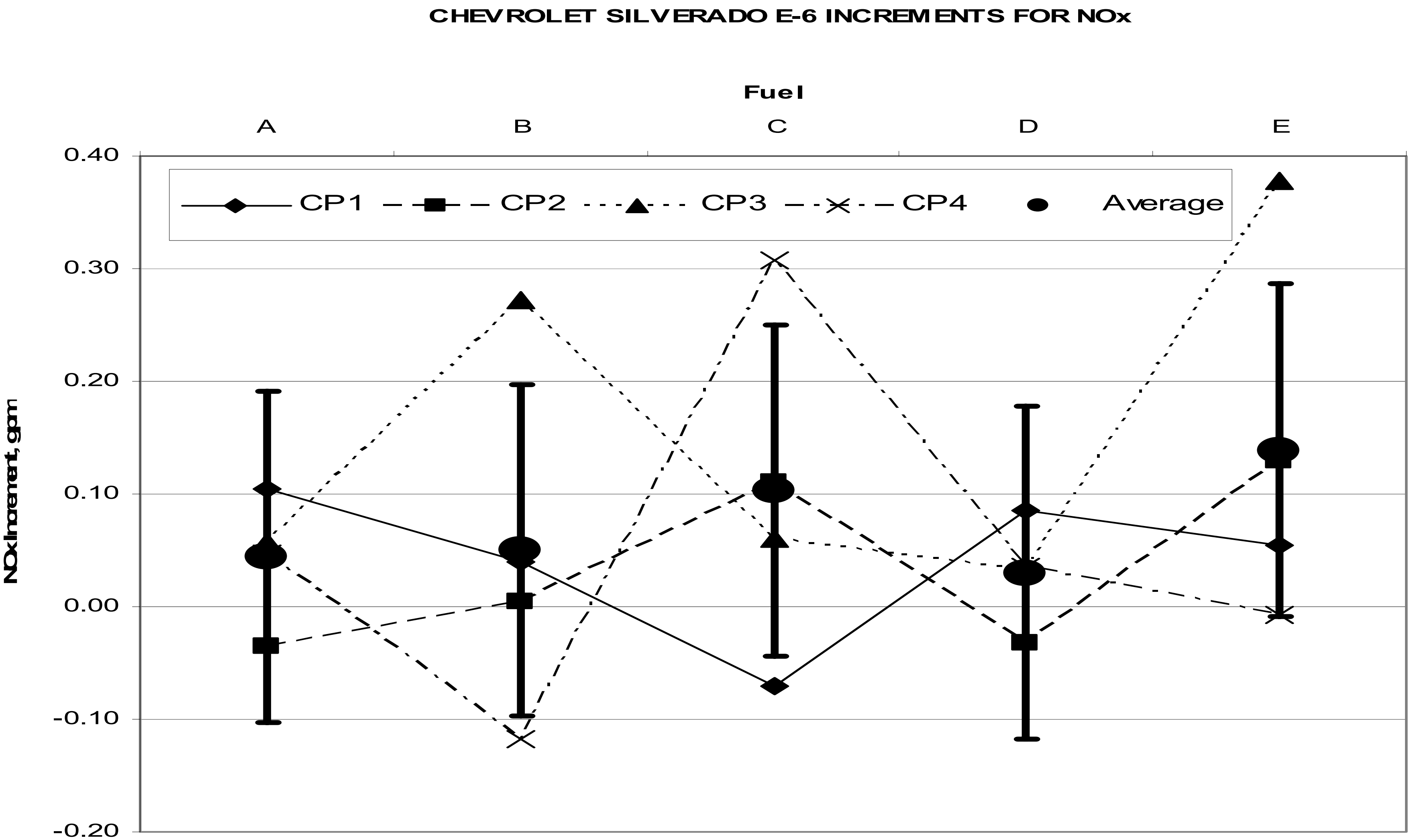


Figure 3 (Figure 33 from Part 1 Report)

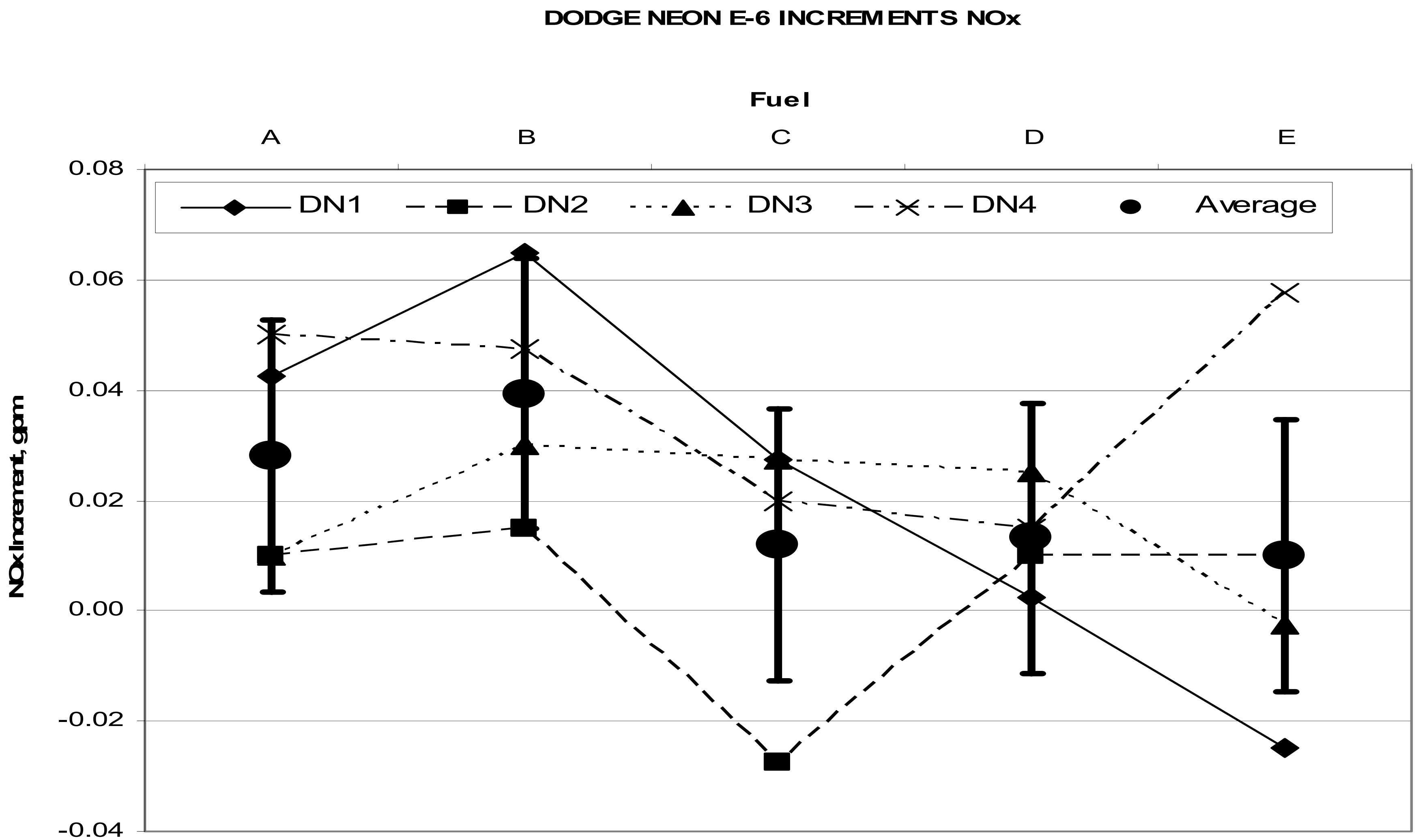


Figure 4 (Figure 37 from Part 1 Report)

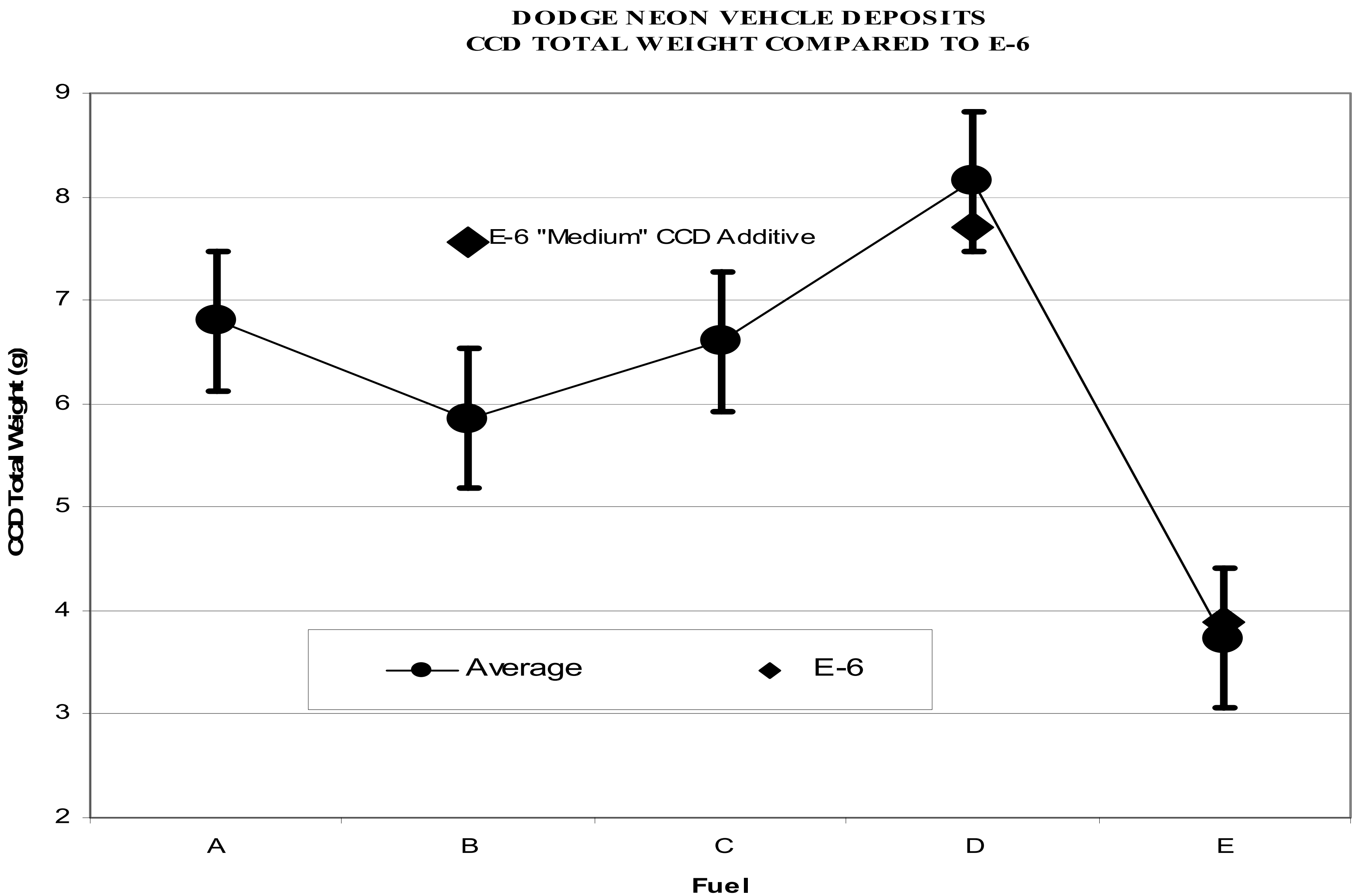

DODGE NEON VEHCLE DEPOSITS
CCD TOTAL WEIGHT COMPARED TO E-6
E-6 "Medium" CCD Additive
Average
E-6
CCD Total Weight (g)
9
8
7
6
5
4
3
2
A
B
C
D
E
Fuel

Figure 5

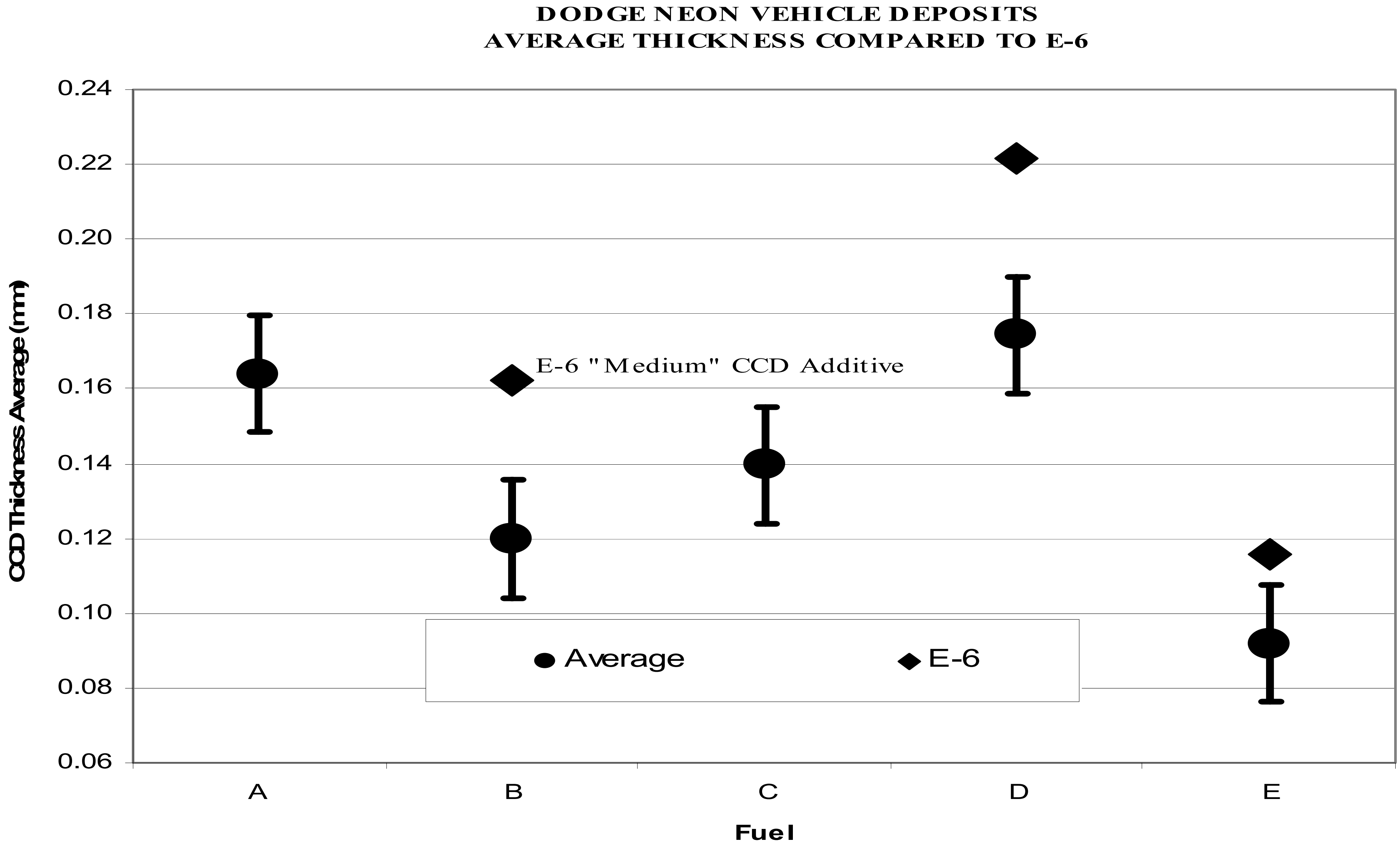

DODGE NEON VEHICLE DEPOSITS
AVERAGE THICKNESS COMPARED TO E-6
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
CCD Thickness Average (mm)
E-6 "Medium" CCD Additive
Average
E-6
A
B
C
D
E
Fuel

Figure 6

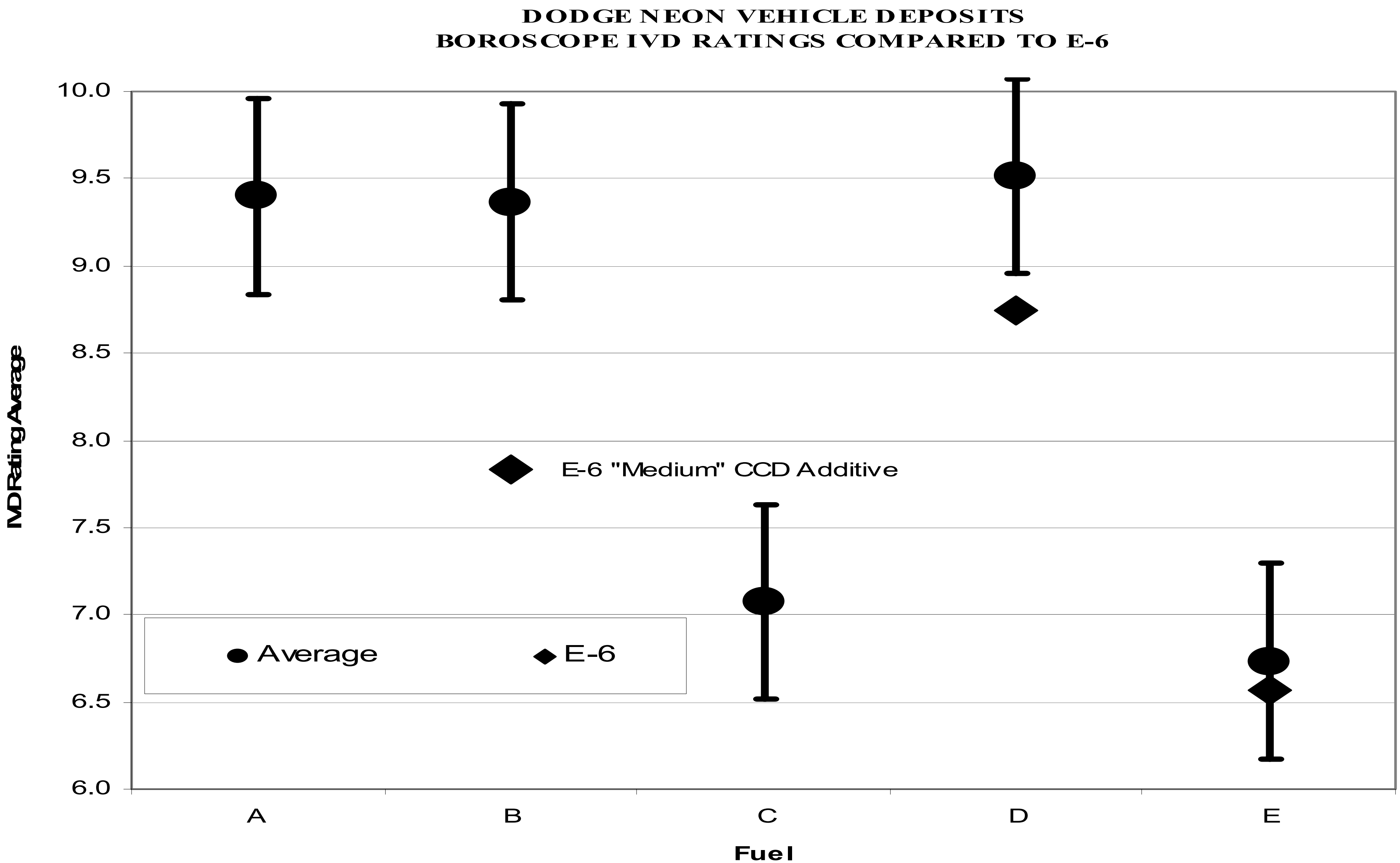
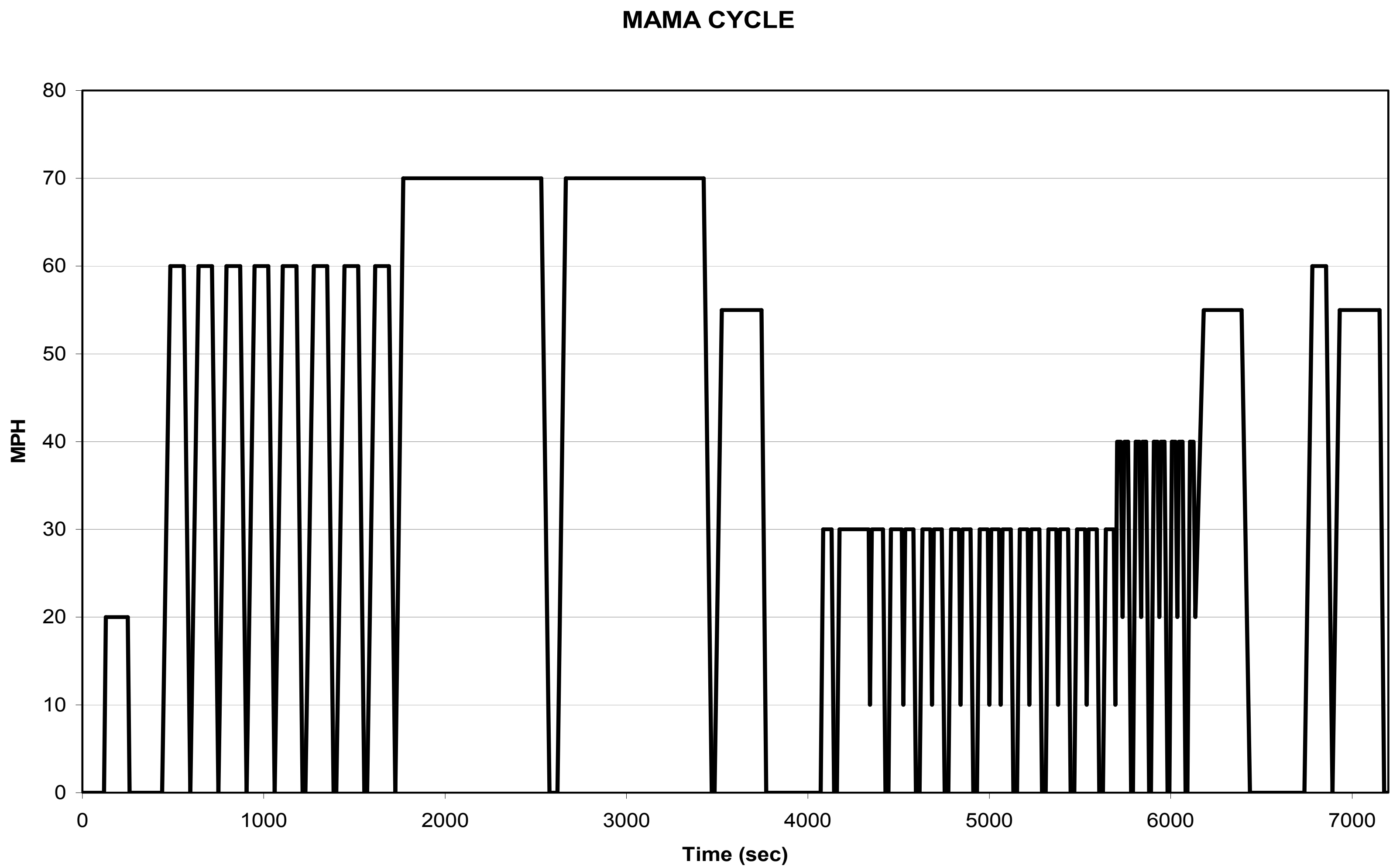

DODGE NEON VEHICLE DEPOSITS
BOROSCOPE IVD RATINGS COMPARED TO E-6
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
IVD Rating Average
E-6 "Medium" CCD Additive
Average
E-6
A
B
C
D
E
Fuel

Figure 7



MAMA CYCLE
MPH
0
10
20
30
40
50
60
70
80
0
1000
2000
3000
4000
5000
6000
7000
Time (sec)

Figure 8

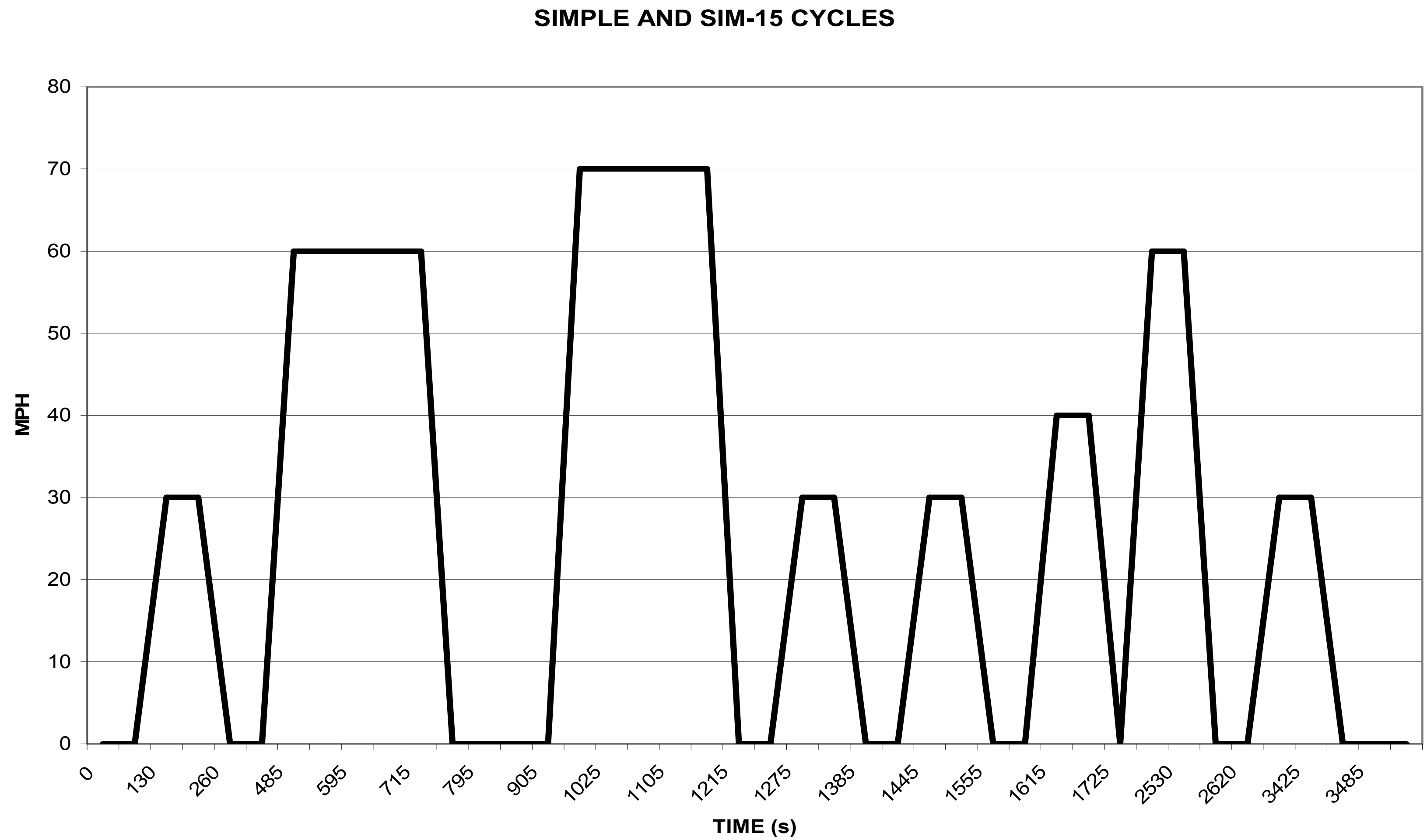

SIMPLE AND SIM-15 CYCLES
MPH
80
70
60
50
40
30
20
10
0
0
130
260
485
595
715
795
905
1025
1105
1215
1275
1385
1445
1555
1615
1725
2530
2620
3425
3485
TIME (s)

Figure 9

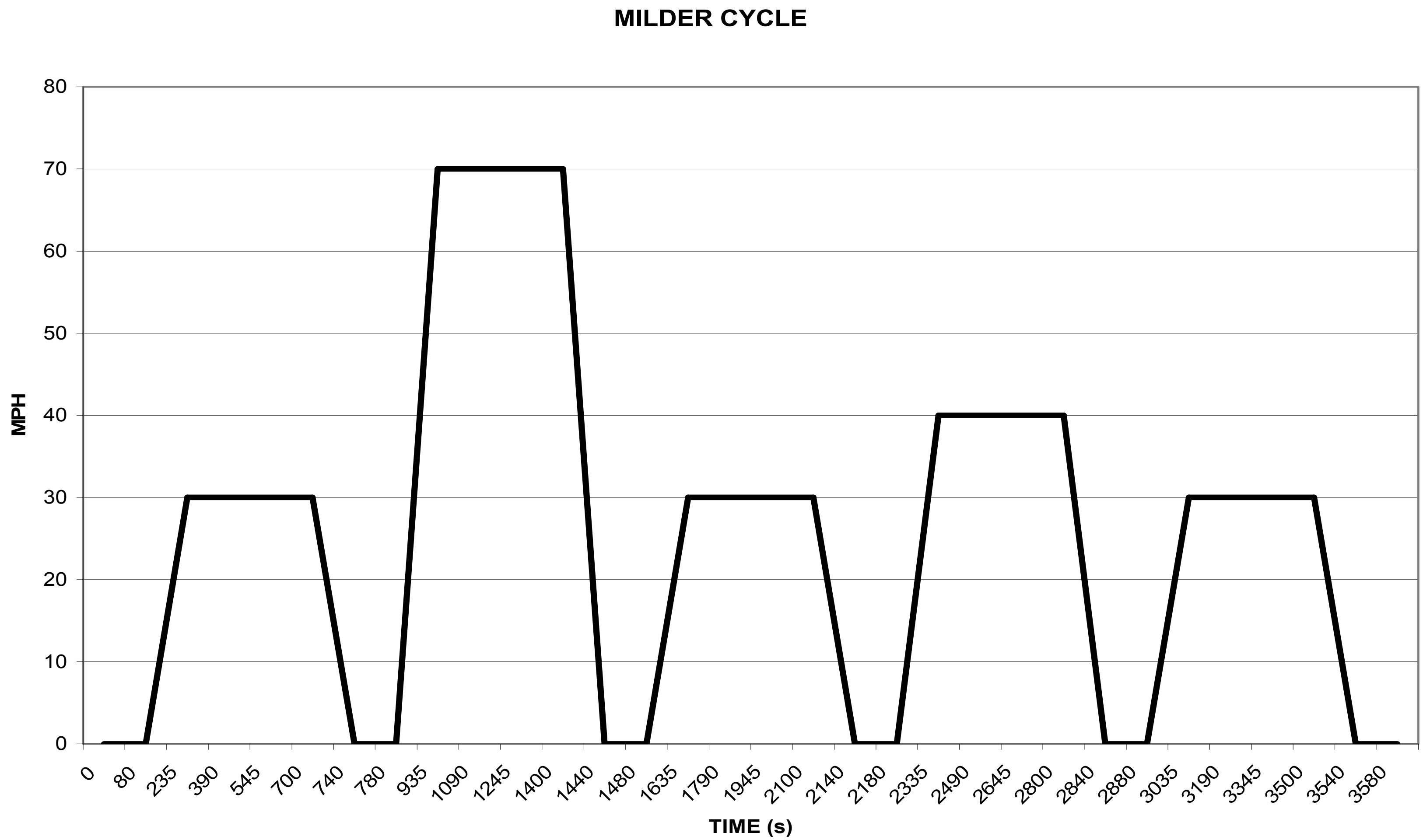

MILDER CYCLE
80
70
60
50
40
30
20
10
0
MPH
0
80
235
390
545
700
740
780
935
1090
1245
1400
1440
1480
1635
1790
1945
2100
2140
2180
2335
2490
2645
2800
2840
2880
3035
3190
3345
3500
3540
3580
TIME (s)

Figure 10

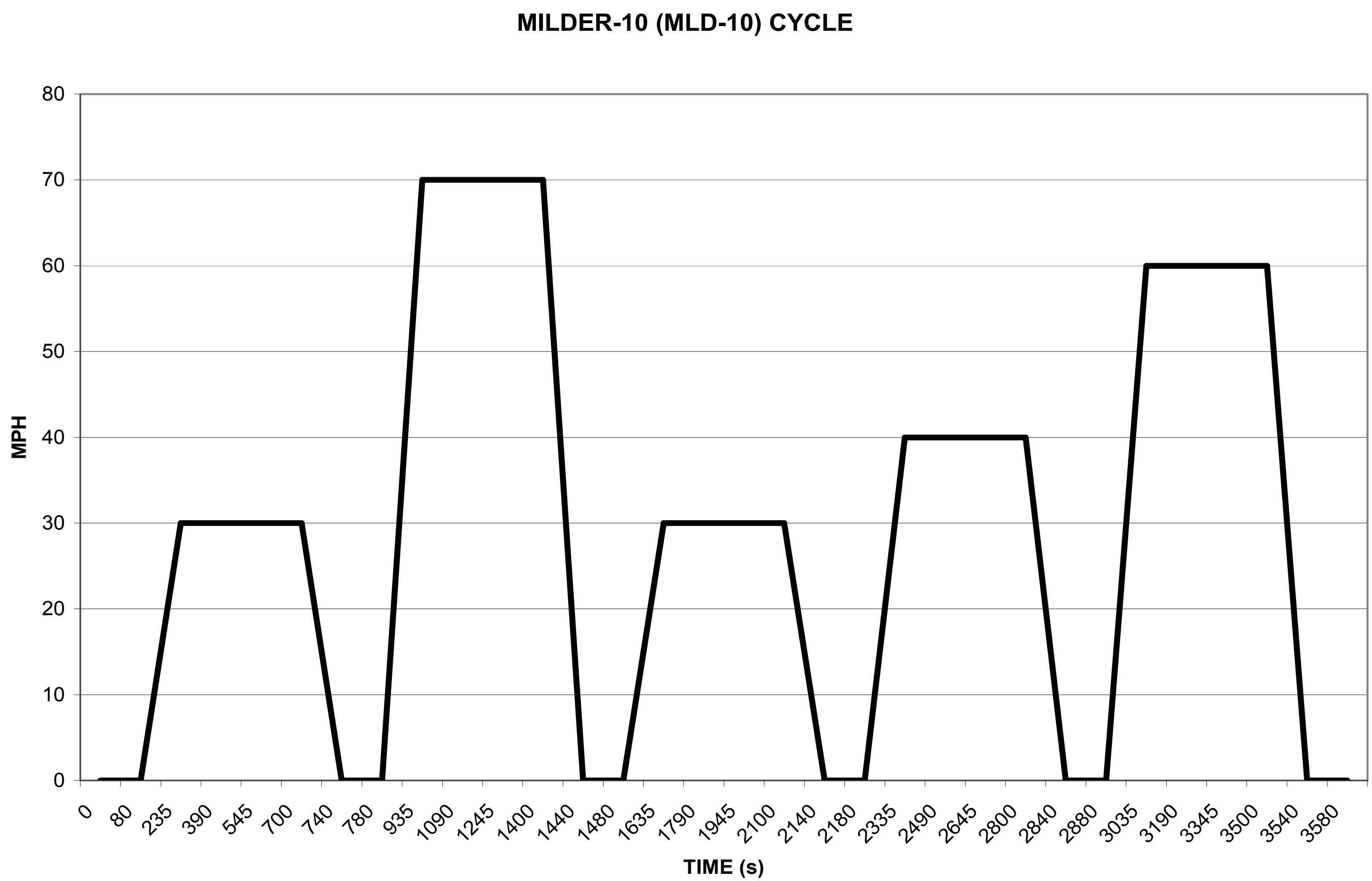
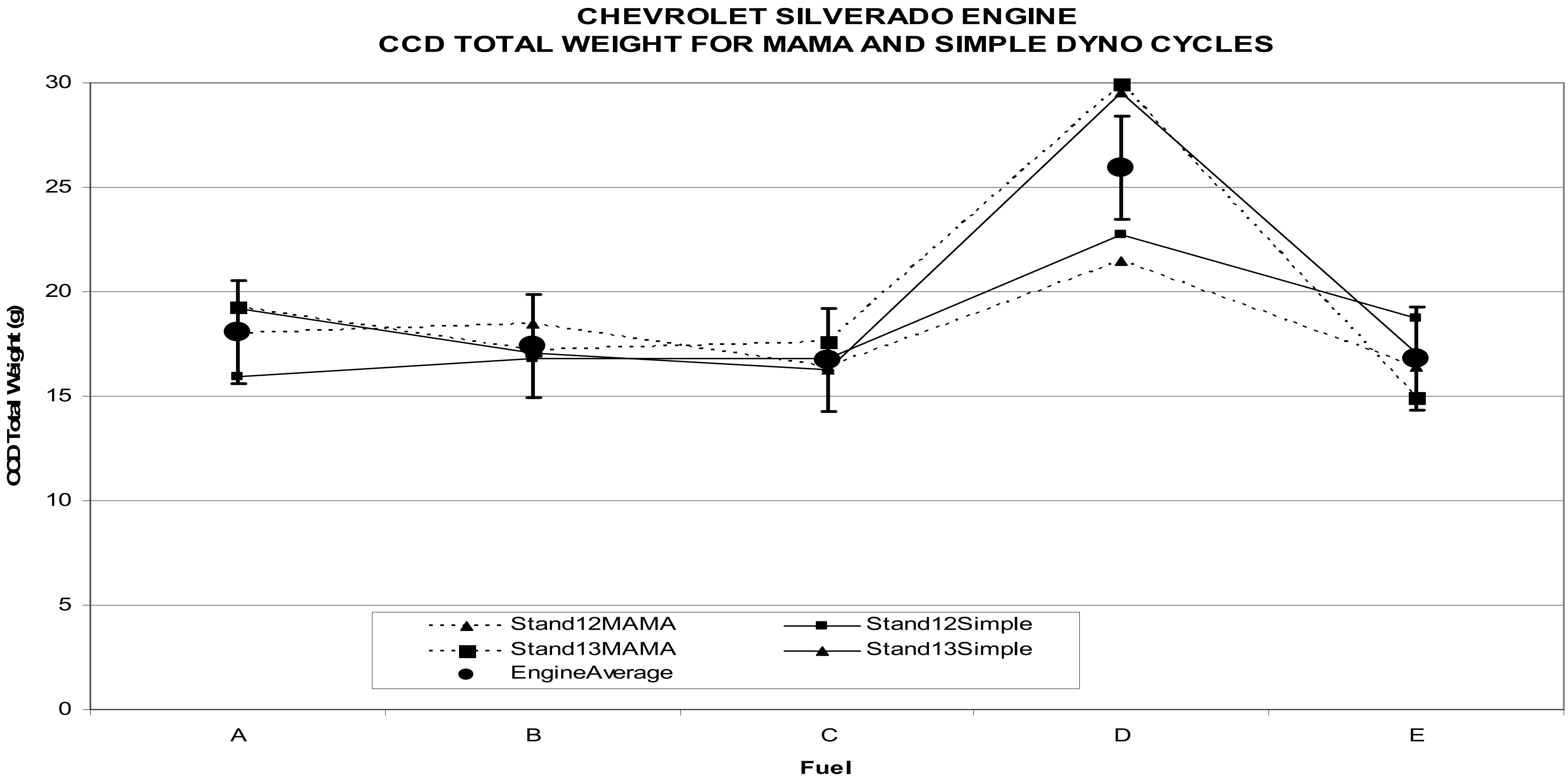

MILDER-10 (MLD-10) CYCLE
MPH
80
70
60
50
40
30
20
10
0
0
80
235
390
545
700
740
780
935
1090
1245
1400
1440
1480
1635
1790
1945
2100
2140
2180
2335
2490
2645
2800
2840
2880
3035
3190
3345
3500
3540
3580
TIME (s)

Figure 11



CHEVROLET SILVERADO ENGINE
CCD TOTAL WEIGHT FOR MAMA AND SIMPLE DYNO CYCLES
30
25
20
15
10
5
0
CCD Total Weight (g)
Stand12MAMA
Stand12Simple
Stand13MAMA
Stand13Simple
EngineAverage
A
B
C
D
E
Fuel

Figure 12

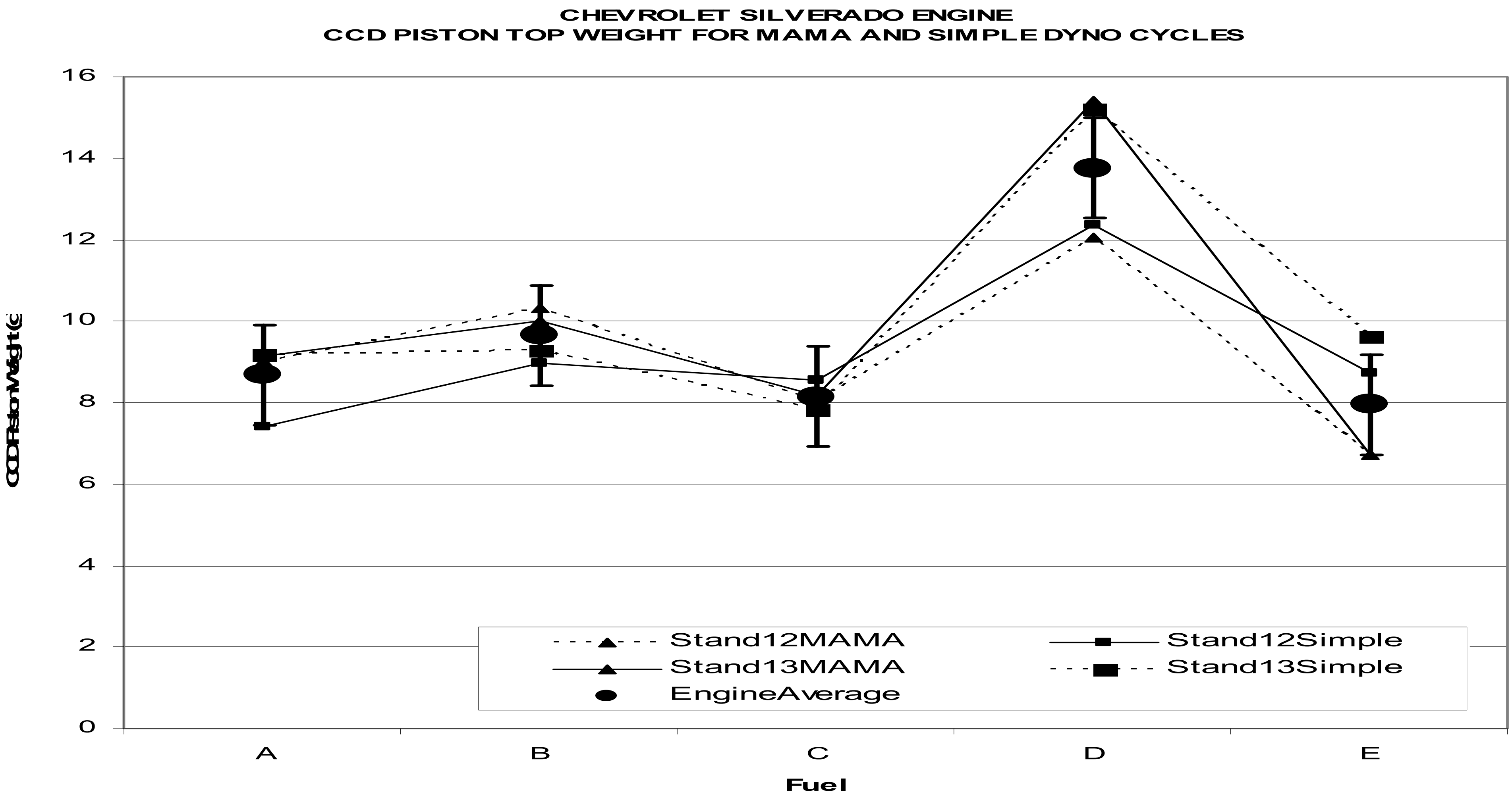
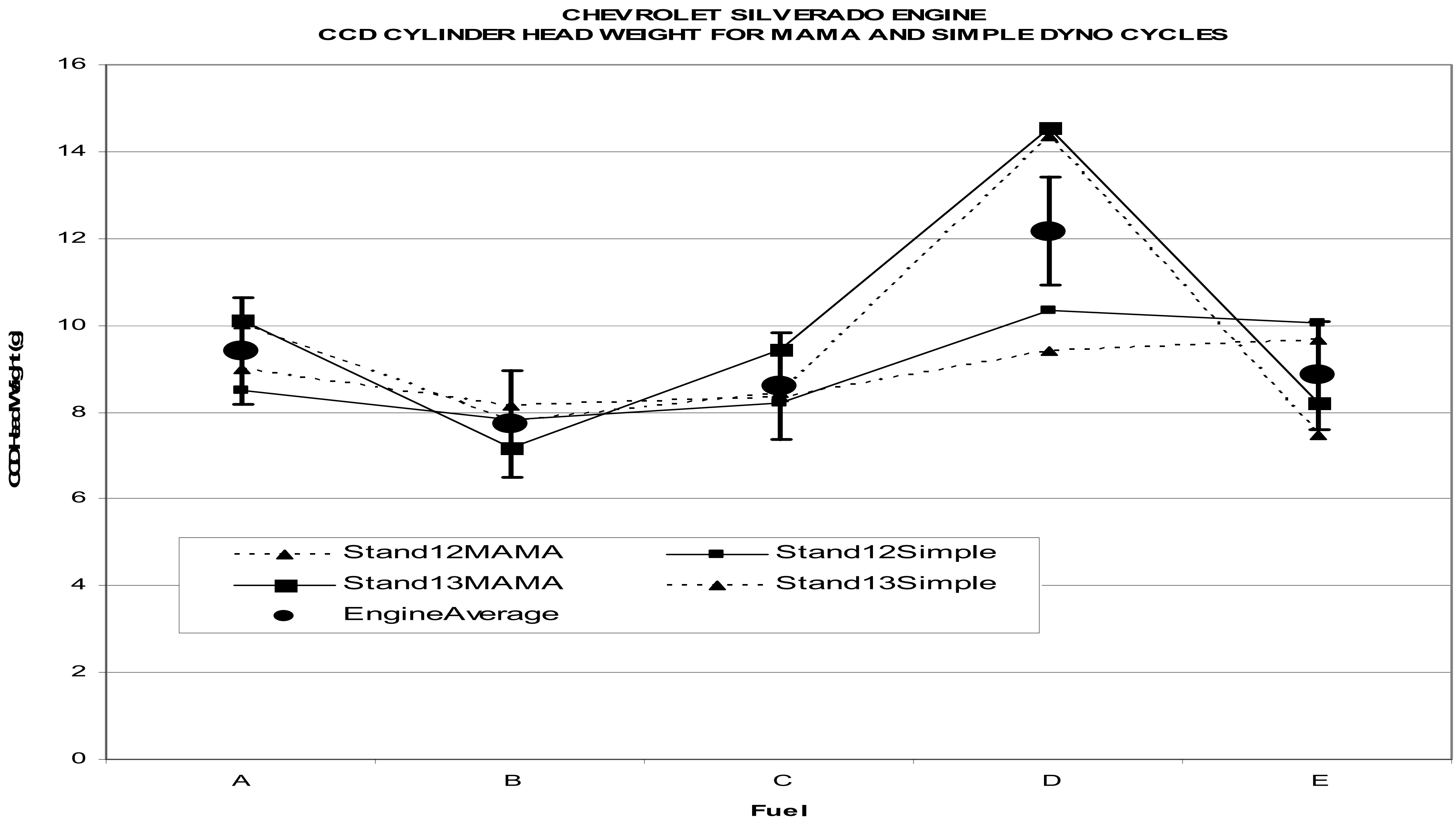

CHEVROLET SILVERADO ENGINE
CCD PISTON TOP WEIGHT FOR MAMA AND SIMPLE DYNO CYCLES
16
14
12
10
8
6
4
2
0
A
B
C
D
E
Fuel
Stand12MAMA
Stand12Simple
Stand13MAMA
Stand13Simple
EngineAverage

Figure 13



CHEVROLET SILVERADO ENGINE
CCD CYLINDER HEAD WEIGHT FOR MAMA AND SIMPLE DYNO CYCLES
CCD Head Weight (g)
0
2
4
6
8
10
12
14
16
A
B
C
D
E
Fuel
Stand12MAMA
Stand12Simple
Stand13MAMA
Stand13Simple
EngineAverage

Figure 14

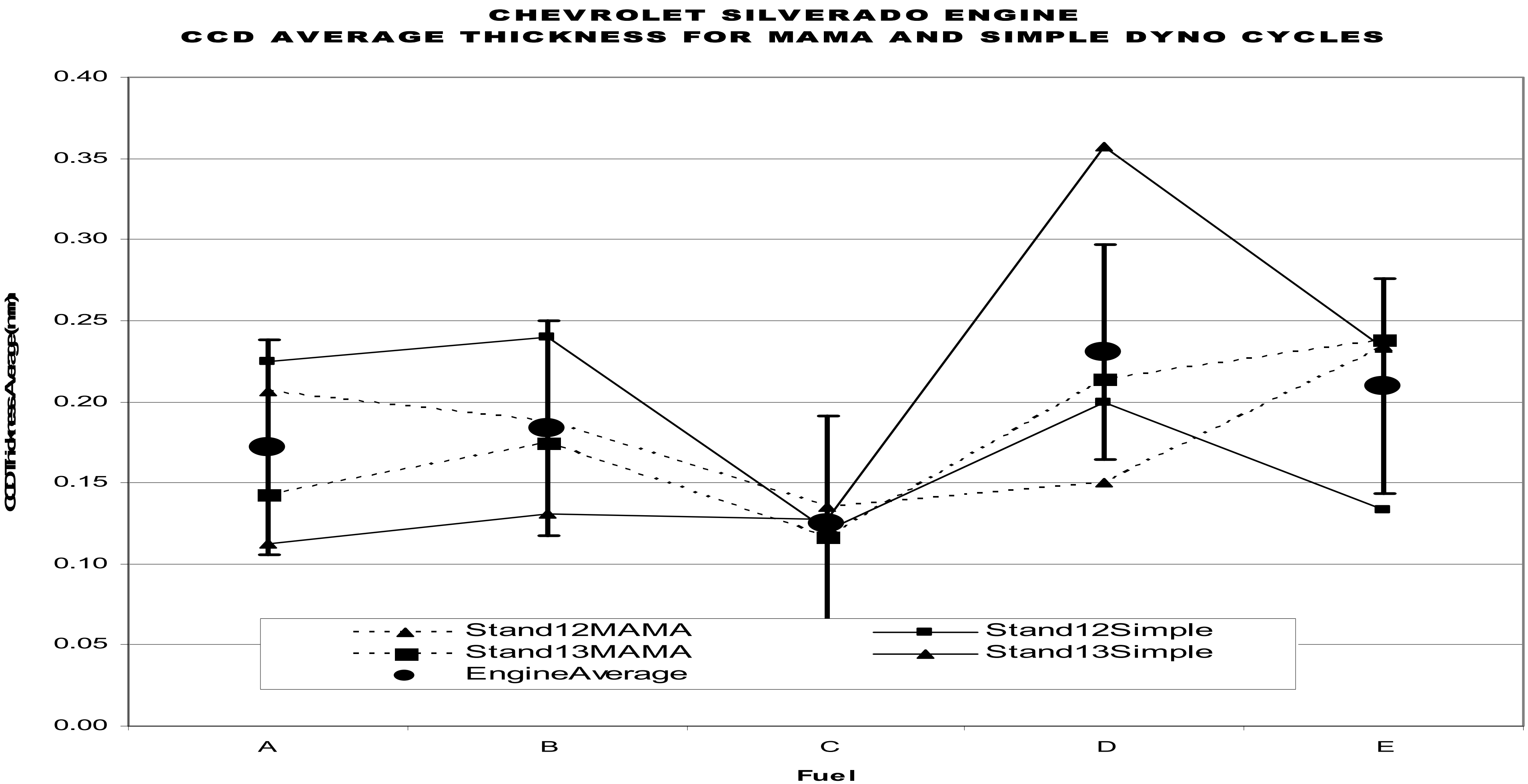

CHEVROLET SILVERADO ENGINE
CCD AVERAGE THICKNESS FOR MAMA AND SIMPLE DYNO CYCLES
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
A
B
C
D
E
Fuel
Stand12MAMA
Stand13MAMA
EngineAverage
Stand12Simple
Stand13Simple

Figure 15

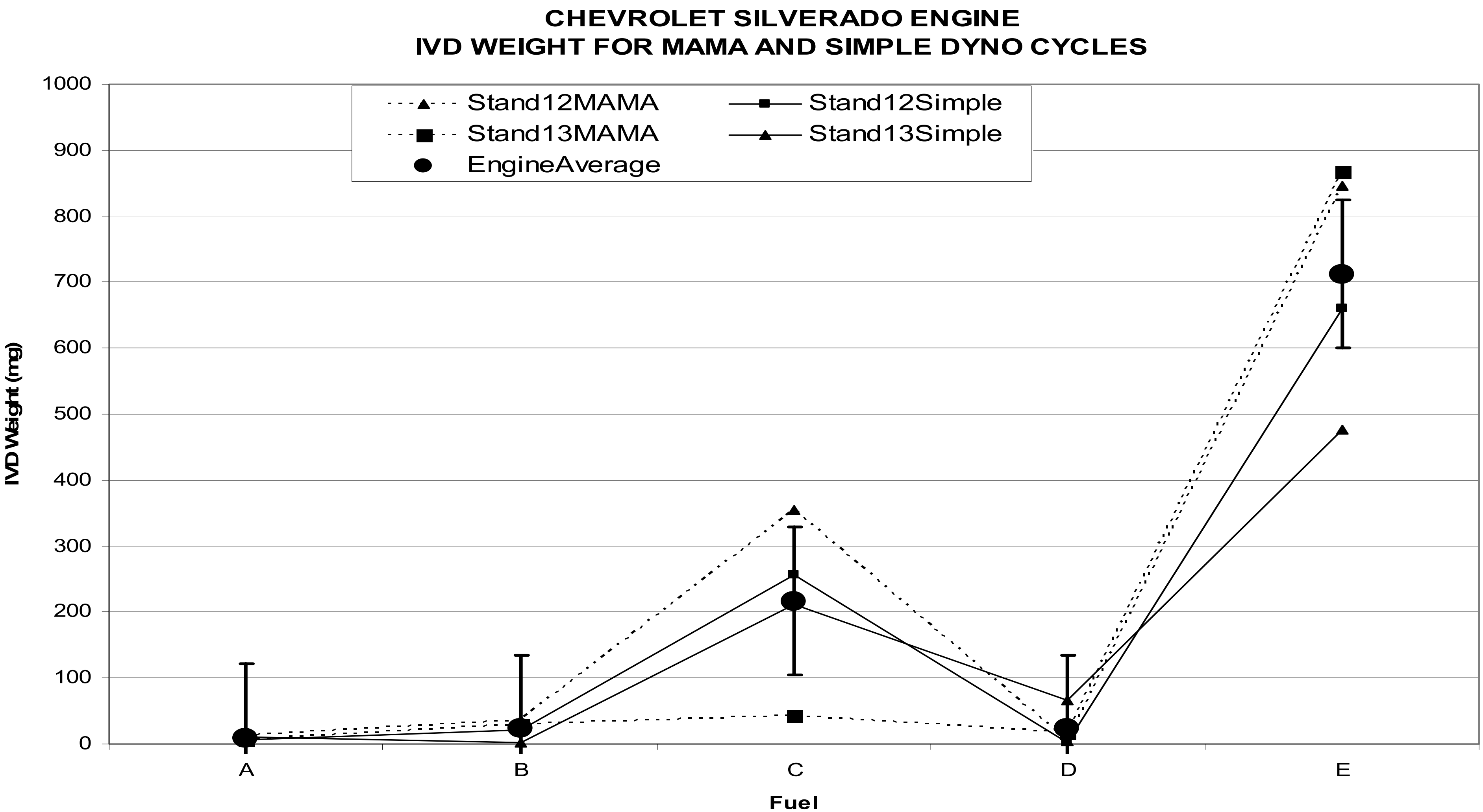

CHEVROLET SILVERADO ENGINE
IVD WEIGHT FOR MAMA AND SIMPLE DYNO CYCLES
Stand12MAMA
Stand12Simple
Stand13MAMA
Stand13Simple
EngineAverage
IVD Weight (mg)
0
100
200
300
400
500
600
700
800
900
1000
A
B
C
D
E
Fuel

Figure 16

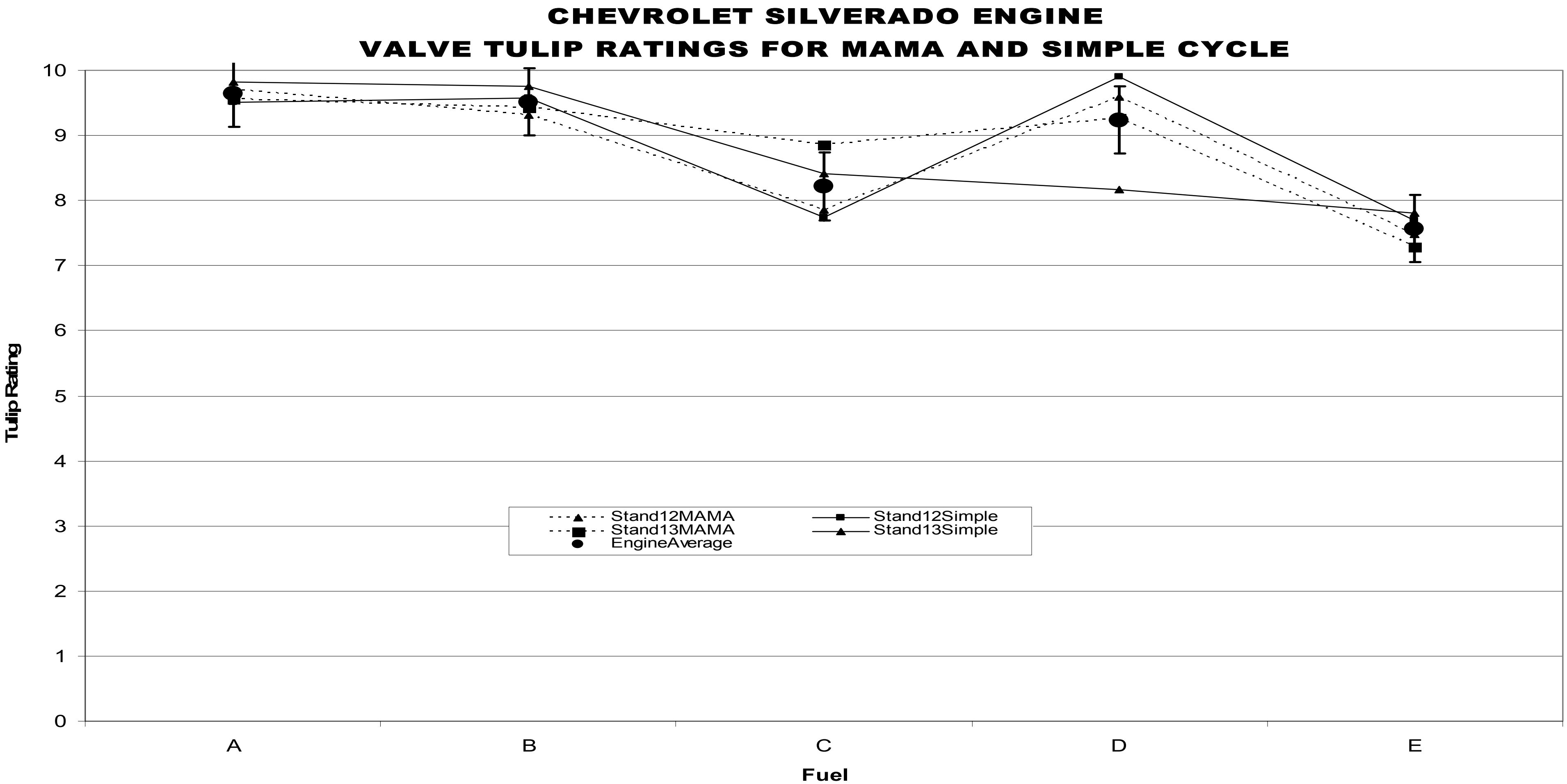

CHEVROLET SILVERADO ENGINE
VALVE TULIP RATINGS FOR MAMA AND SIMPLE CYCLE
Tulip Rating
10
9
8
7
6
5
4
3
2
1
0
A
B
C
D
E
Fuel
Stand12MAMA
Stand13MAMA
EngineAverage
Stand12Simple
Stand13Simple

Figure 17

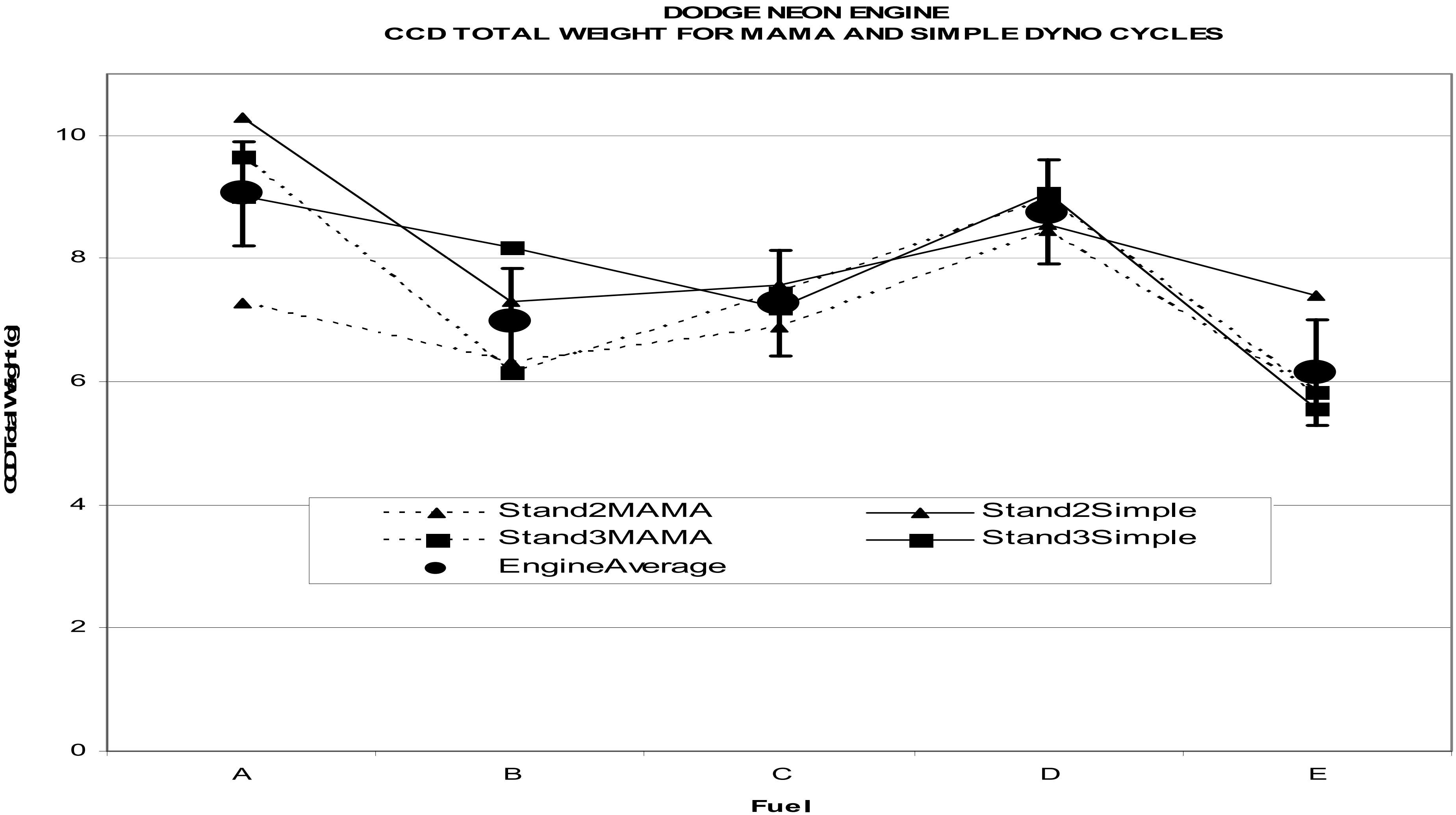

DODGE NEON ENGINE
CCD TOTAL WEIGHT FOR MAMA AND SIMPLE DYNO CYCLES
CCD Total Weight (g)
10
8
6
4
2
0
Stand2MAMA
Stand2Simple
Stand3MAMA
Stand3Simple
EngineAverage
A
B
C
D
E
Fuel

Figure 18

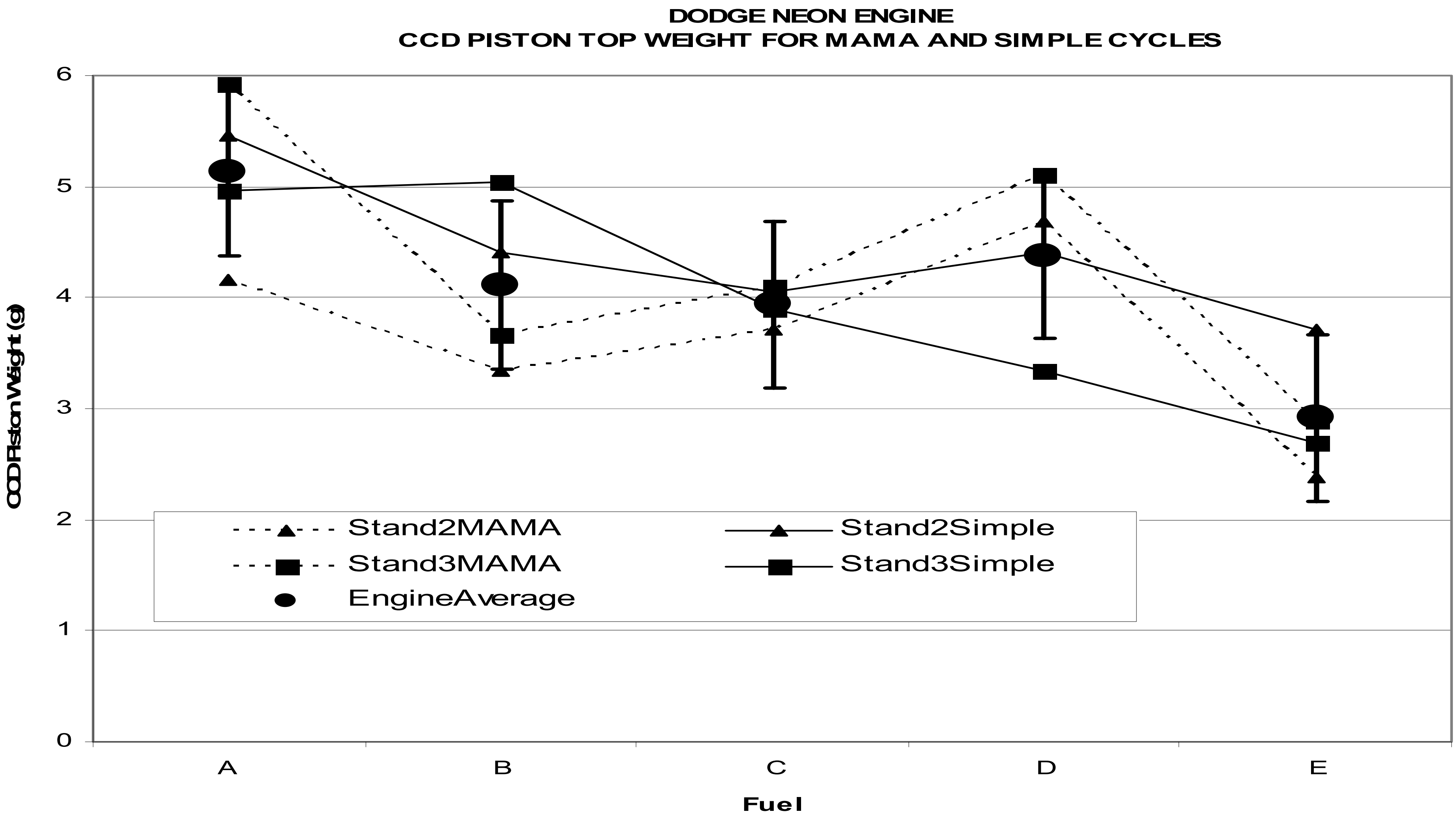

DODGE NEON ENGINE
CCD PISTON TOP WEIGHT FOR MAMA AND SIMPLE CYCLES
CCD Piston Weight (g)
6
5
4
3
2
1
0
A
B
C
D
E
Fuel
Stand2MAMA
Stand2Simple
Stand3MAMA
Stand3Simple
EngineAverage

Figure 19

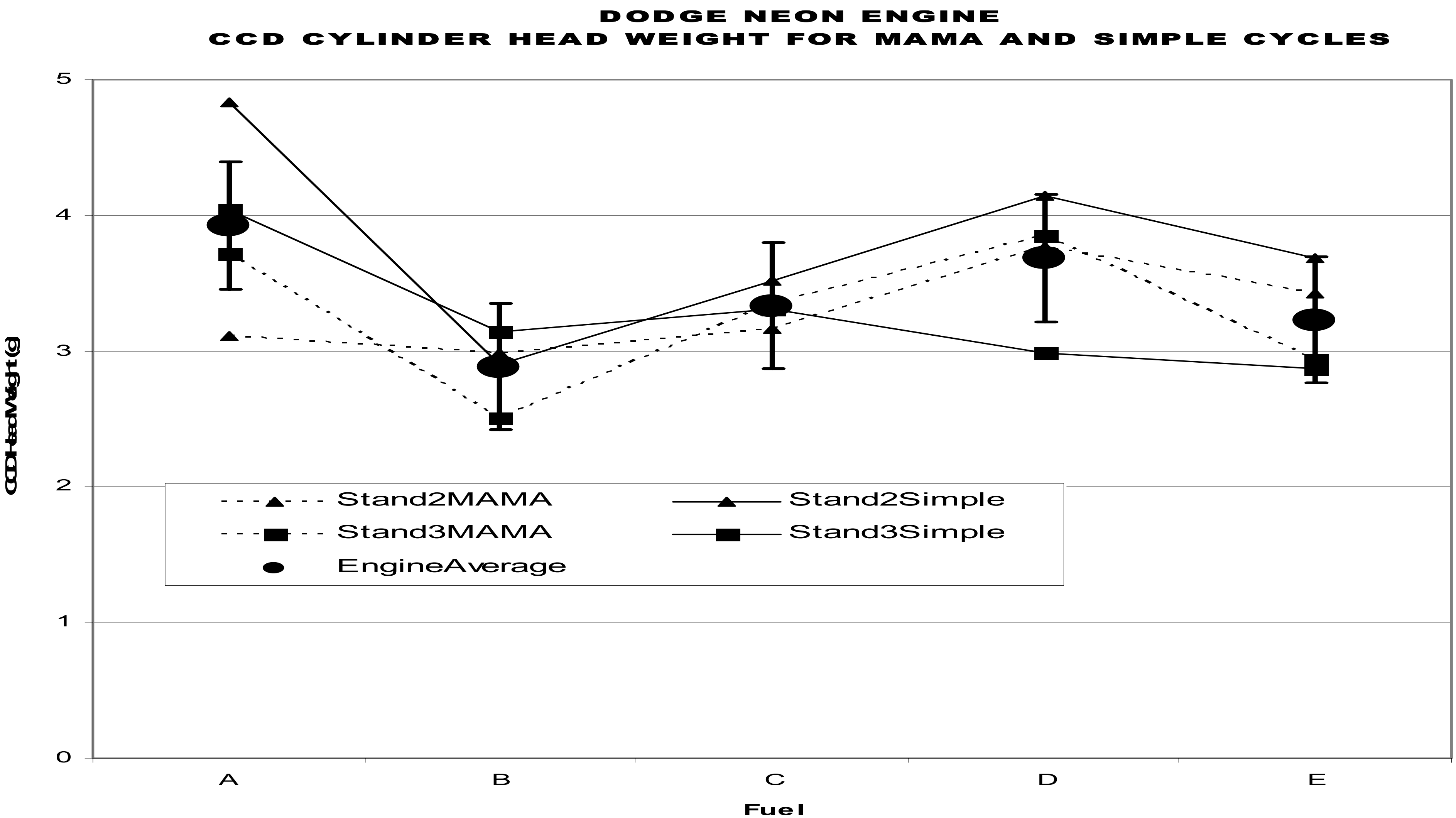

DODGE NEON ENGINE
CCD CYLINDER HEAD WEIGHT FOR MAMA AND SIMPLE CYCLES
0
1
2
3
4
5
A
B
C
D
E
Fuel
Stand2MAMA
Stand2Simple
Stand3MAMA
Stand3Simple
EngineAverage

Figure 20

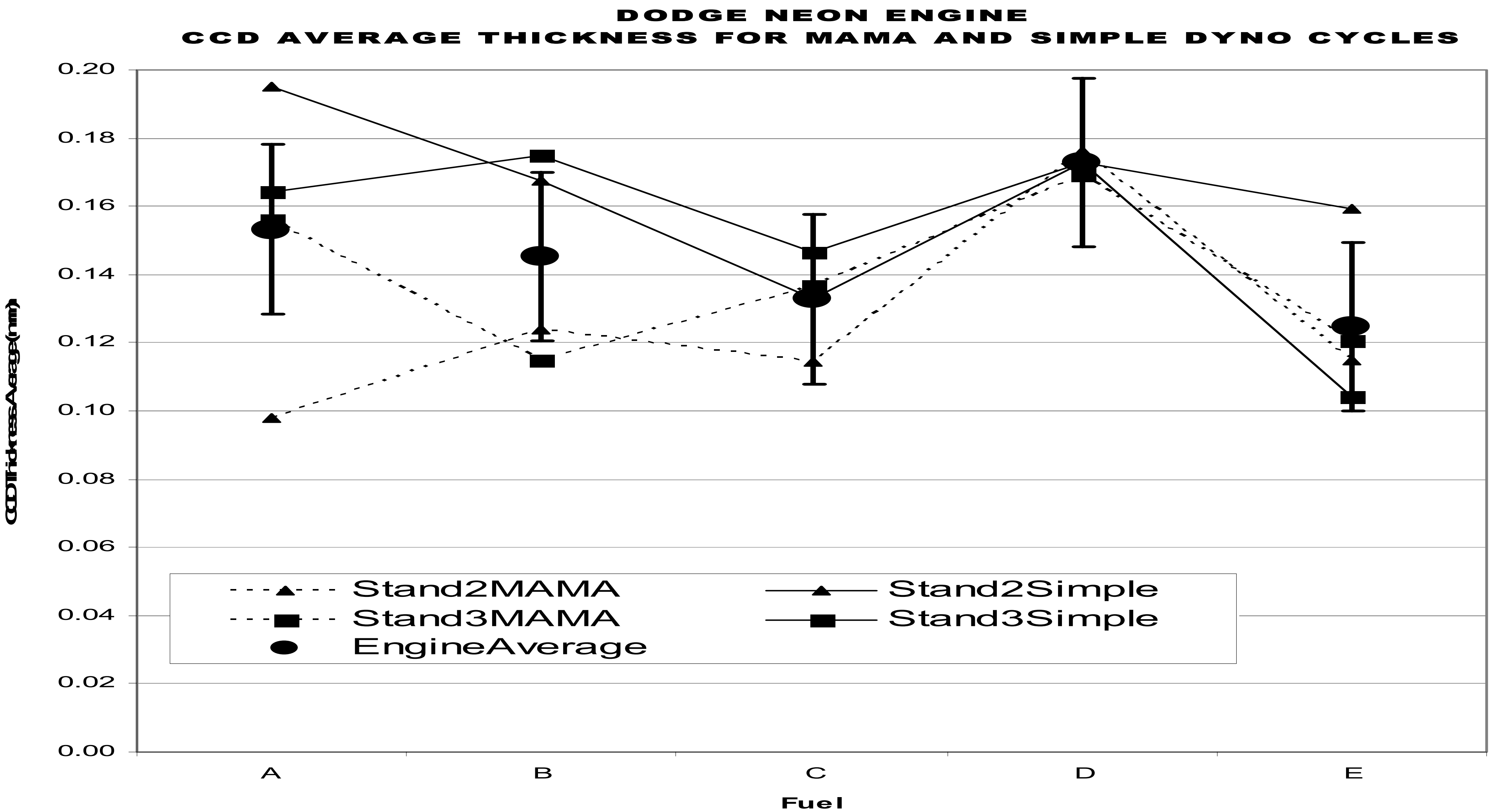

DODGE NEON ENGINE
CCD AVERAGE THICKNESS FOR MAMA AND SIMPLE DYNO CYCLES
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
A
B
C
D
E
Fuel
Stand2MAMA
Stand2Simple
Stand3MAMA
Stand3Simple
EngineAverage

Figure 21

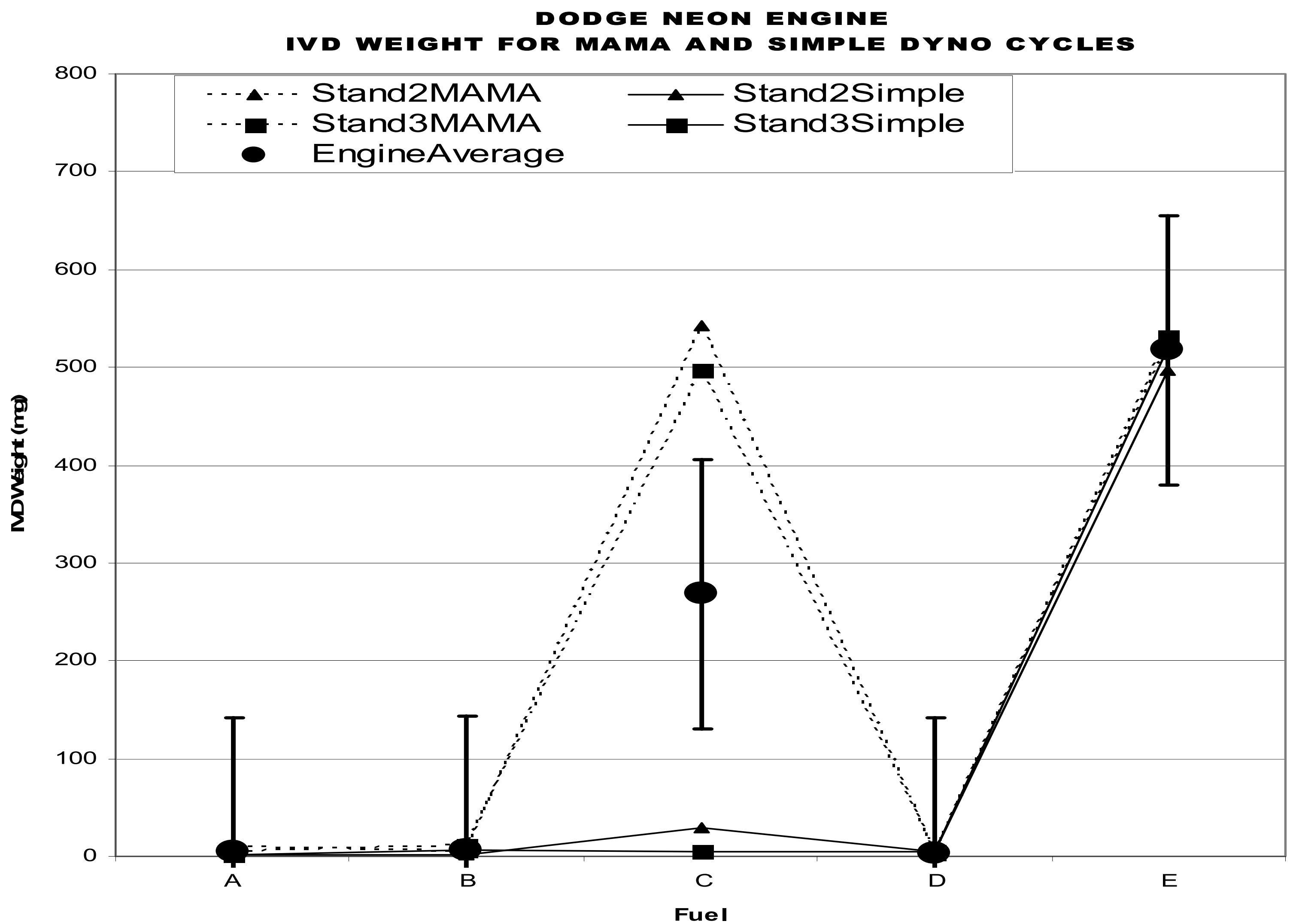
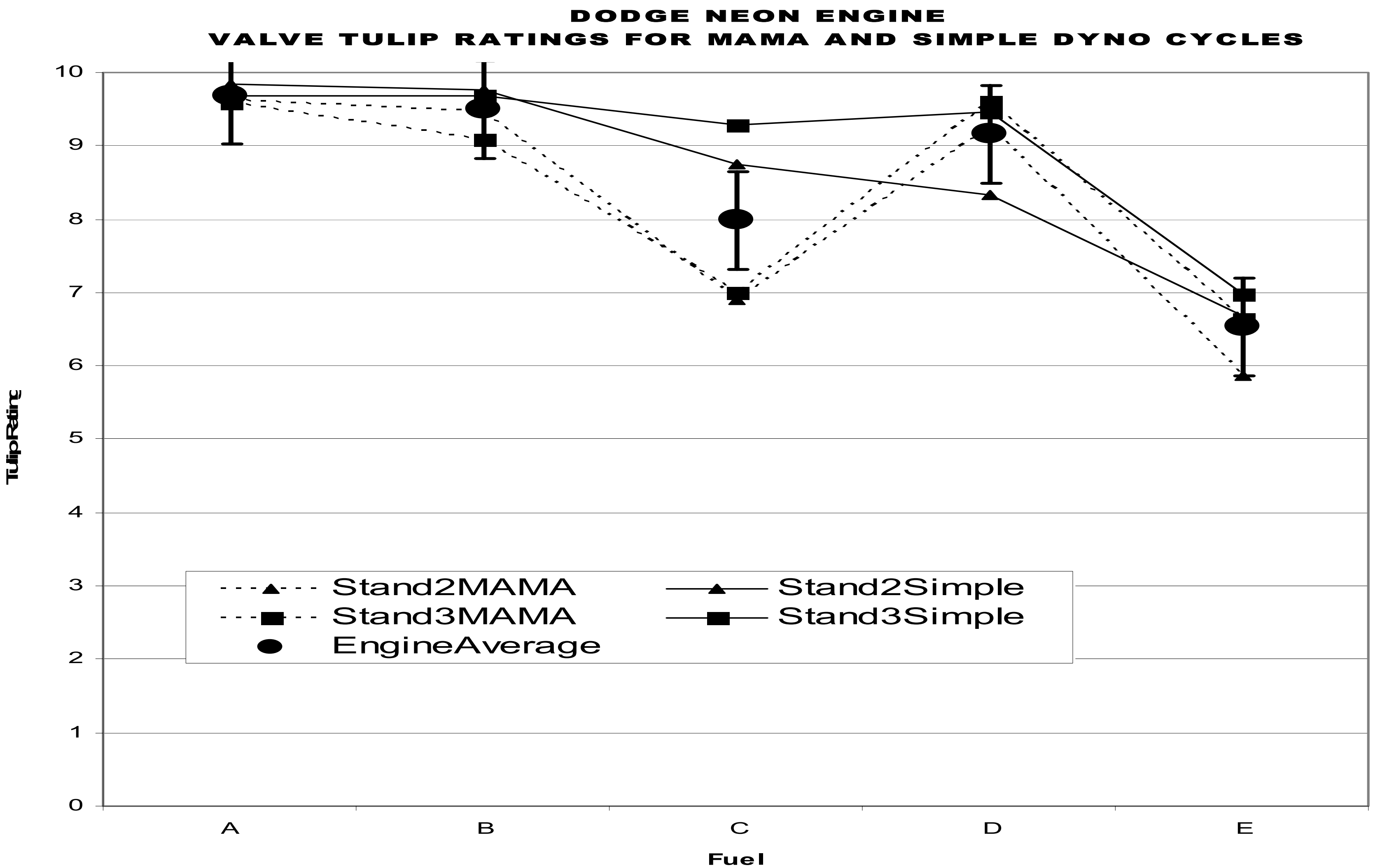

DODGE NEON ENGINE
IVD WEIGHT FOR MAMA AND SIMPLE DYNO CYCLES
Stand2MAMA
Stand2Simple
Stand3MAMA
Stand3Simple
EngineAverage
800
700
600
500
400
300
200
100
0
IVD Weight (mg)
A
B
C
D
E
Fuel

Figure 22



DODGE NEON ENGINE
VALVE TULIP RATINGS FOR MAMA AND SIMPLE DYNO CYCLES
10
9
8
7
6
5
4
3
2
1
0
Tulip Rating
A
B
C
D
E
Fuel
Stand2MAMA
Stand2Simple
Stand3MAMA
Stand3Simple
EngineAverage

Figure 23

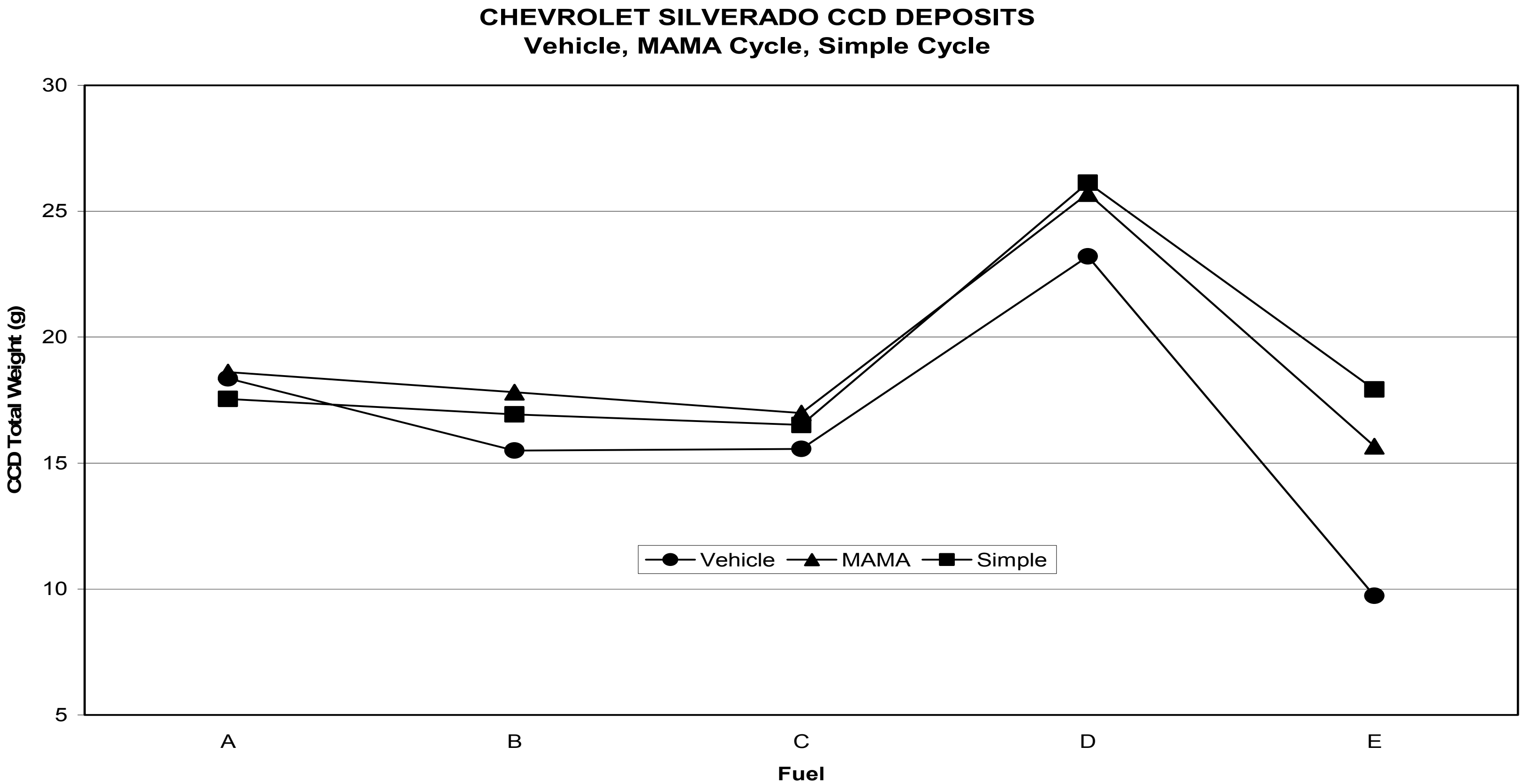

CHEVROLET SILVERADO CCD DEPOSITS
Vehicle, MAMA Cycle, Simple Cycle
CCD Total Weight (g)
30
25
20
15
10
5
A
B
C
D
E
Fuel
Vehicle
MAMA
Simple

Figure 24

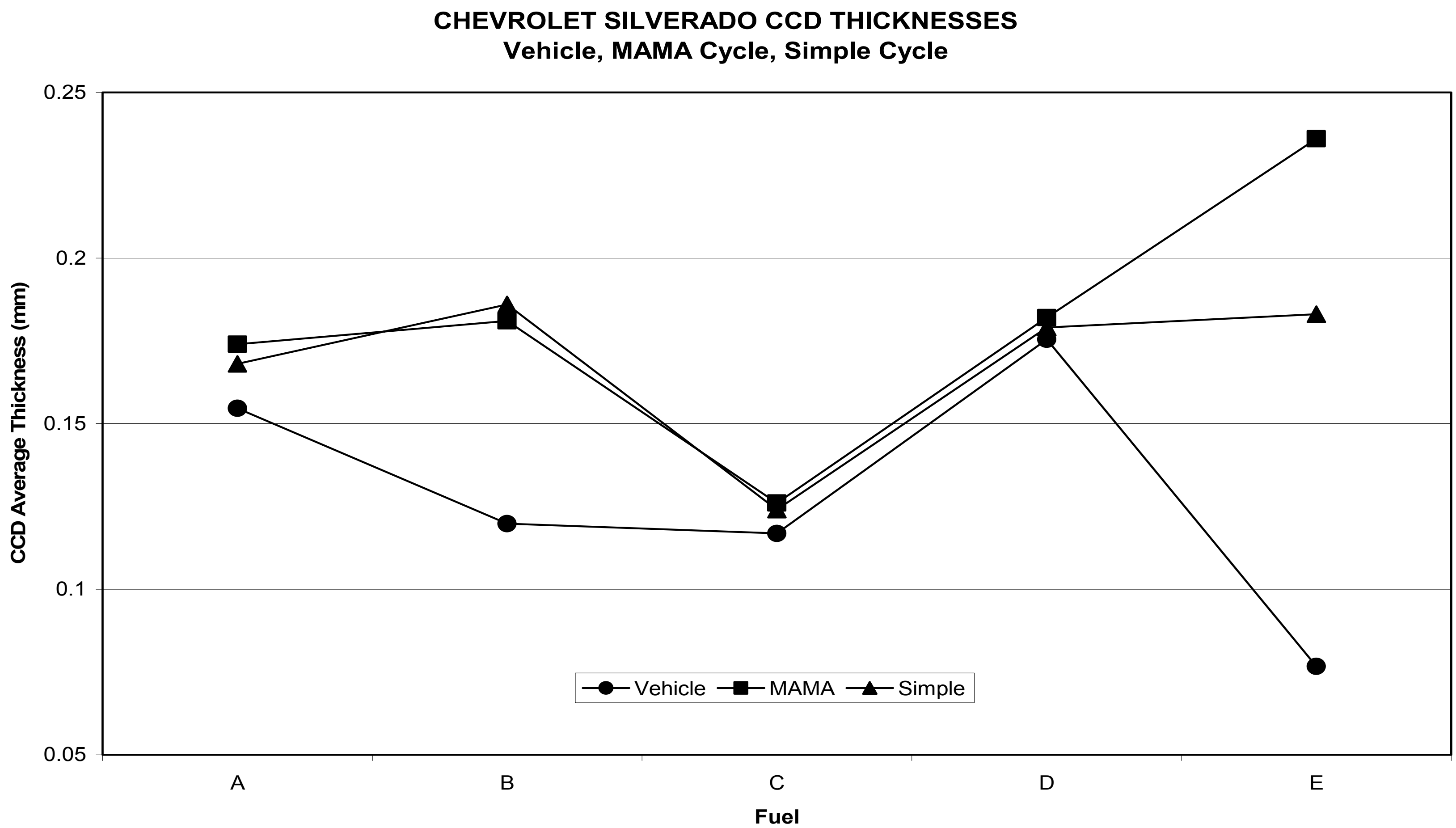

CHEVROLET SILVERADO CCD THICKNESSES
Vehicle, MAMA Cycle, Simple Cycle
CCD Average Thickness (mm)
0.25
0.2
0.15
0.1
0.05
A
B
C
D
E
Fuel
Vehicle
MAMA
Simple

Figure 25

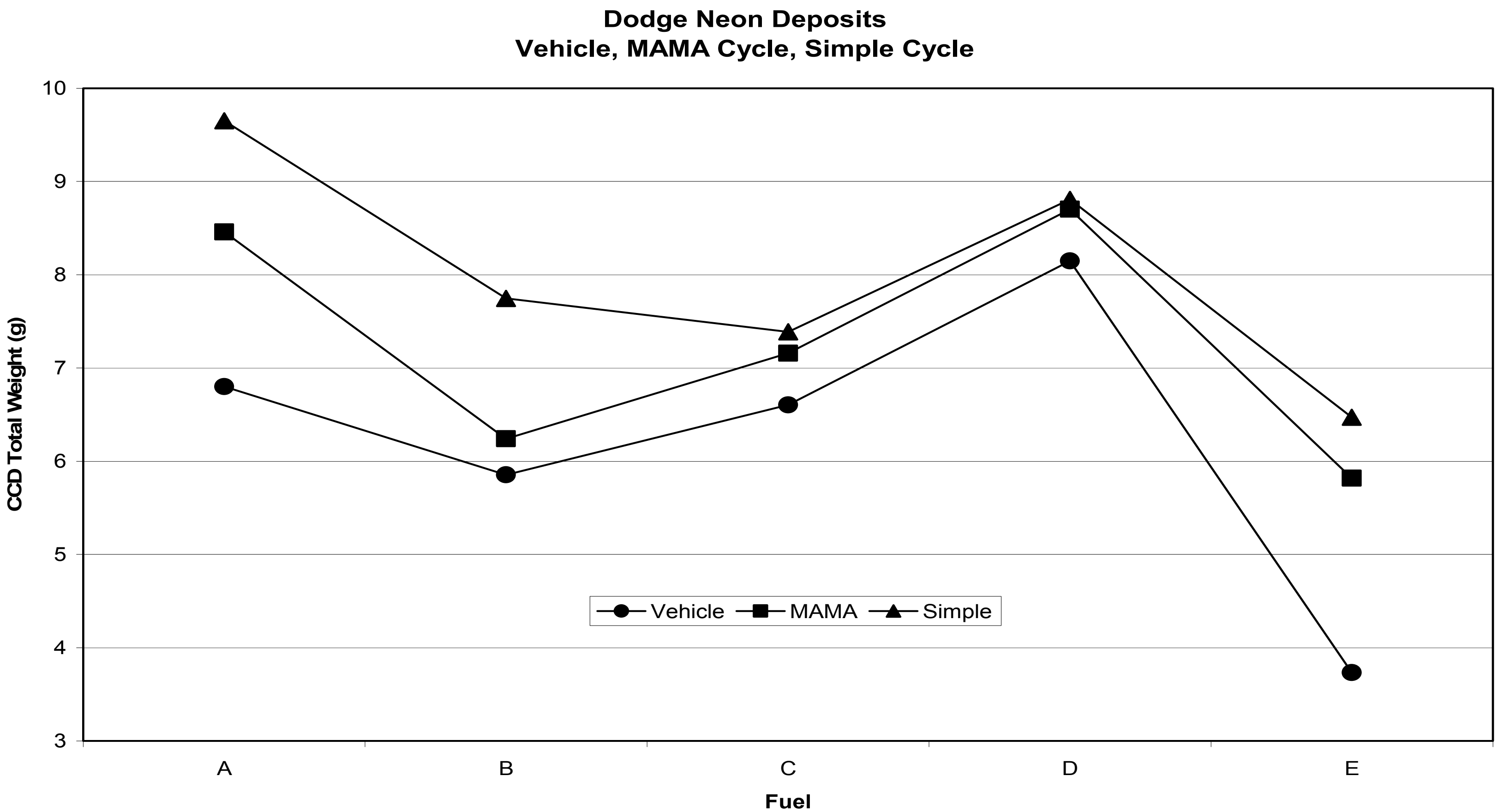

Dodge Neon Deposits
Vehicle, MAMA Cycle, Simple Cycle
CCD Total Weight (g)
10
9
8
7
6
5
4
3
A
B
C
D
E
Fuel
Vehicle
MAMA
Simple

Figure 26

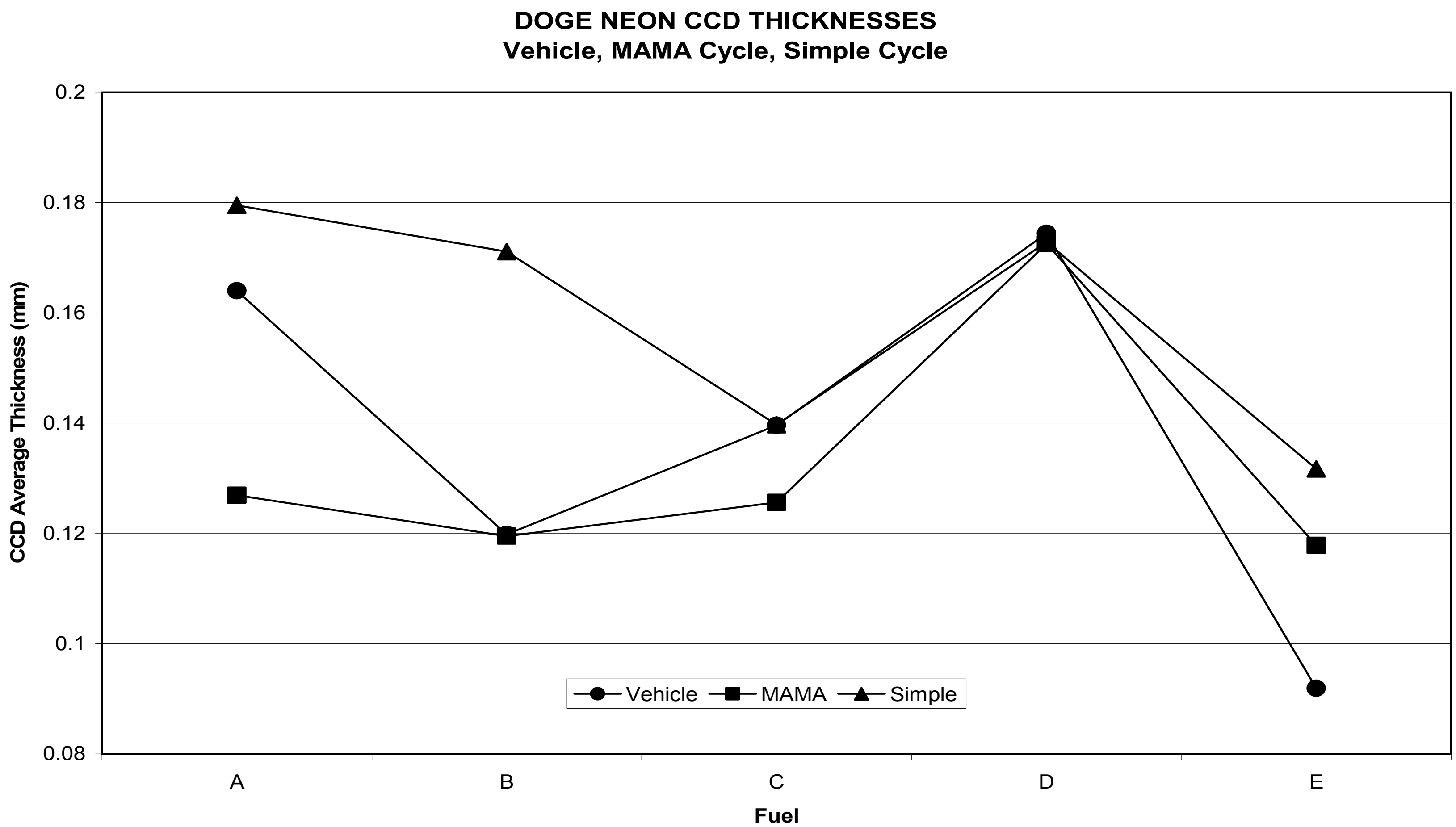

DOGE NEON CCD THICKNESSES
Vehicle, MAMA Cycle, Simple Cycle
CCD Average Thickness (mm)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
Vehicle
MAMA
Simple
A
B
C
D
E
Fuel

Figure 27

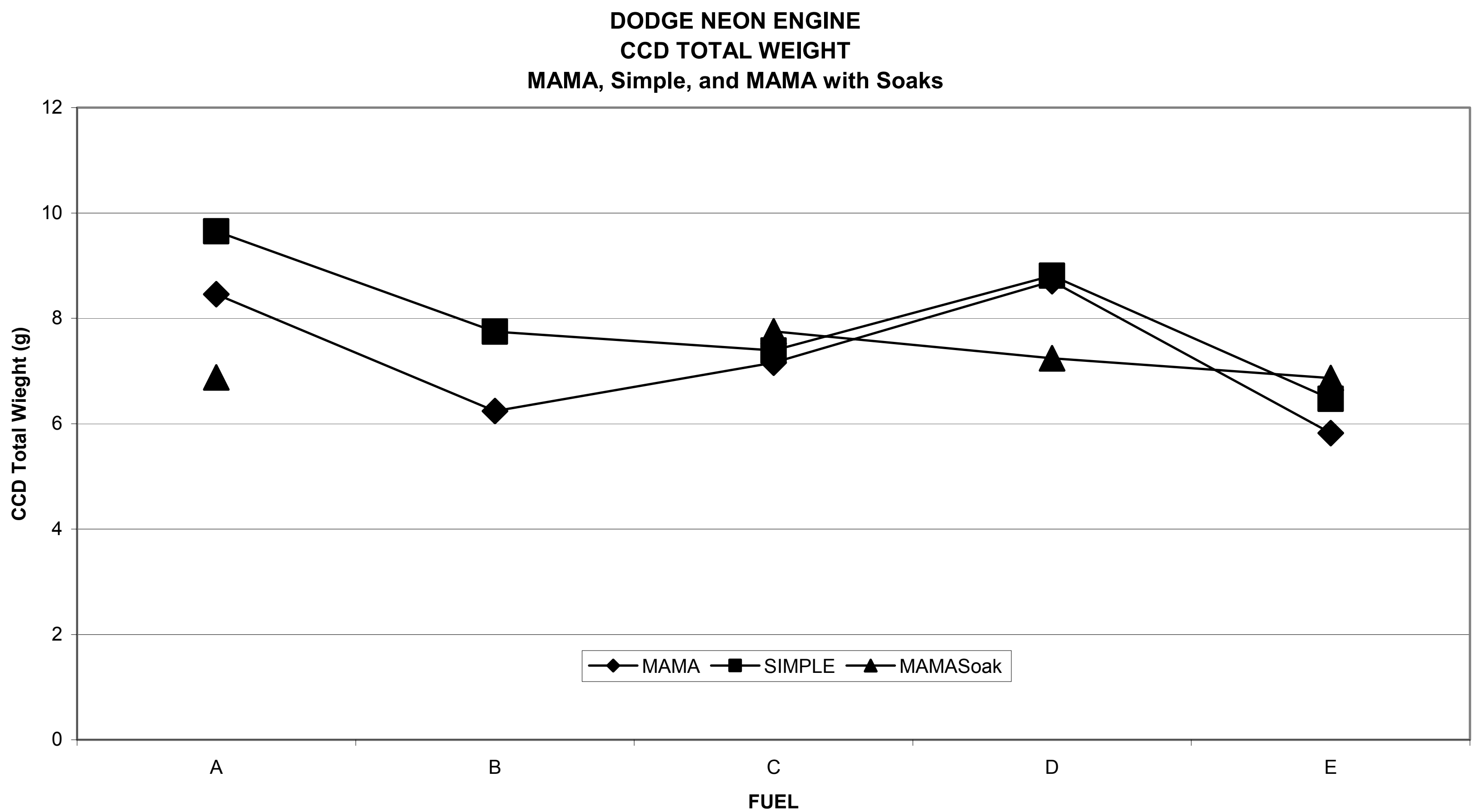

DODGE NEON ENGINE
CCD TOTAL WEIGHT
MAMA, Simple, and MAMA with Soaks
CCD Total Wieght (g)
12
10
8
6
4
2
0
A
B
C
D
E
FUEL
MAMA
SIMPLE
MAMASoak

Figure 28

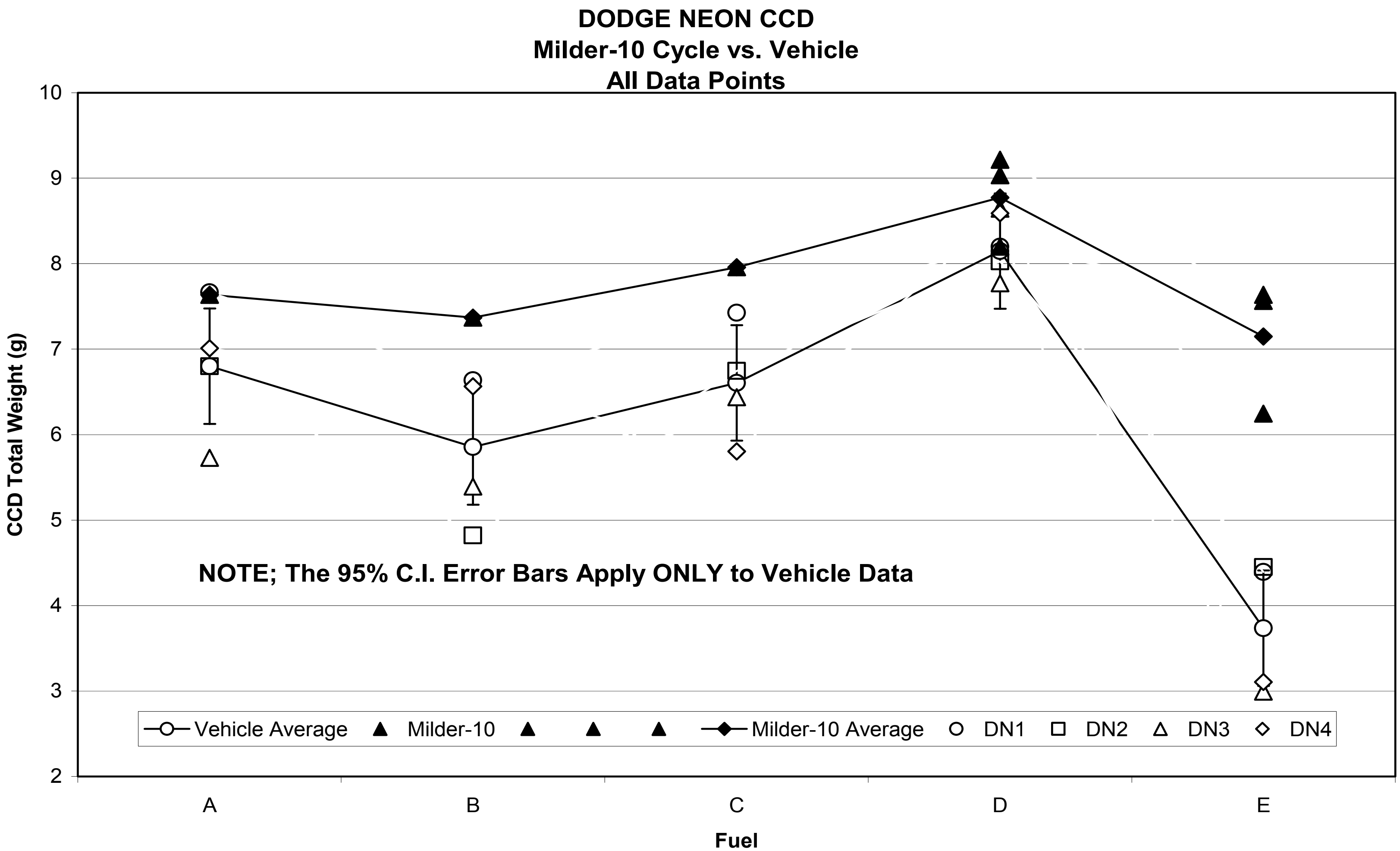

DODGE NEON CCD
Milder-10 Cycle vs. Vehicle
All Data Points
CCD Total Weight (g)
10
9
8
7
6
5
4
3
2
NOTE; The 95% C.I. Error Bars Apply ONLY to Vehicle Data
Vehicle Average
Milder-10
Milder-10 Average
DN1
DN2
DN3
DN4
A
B
C
D
E
Fuel

Figure 29

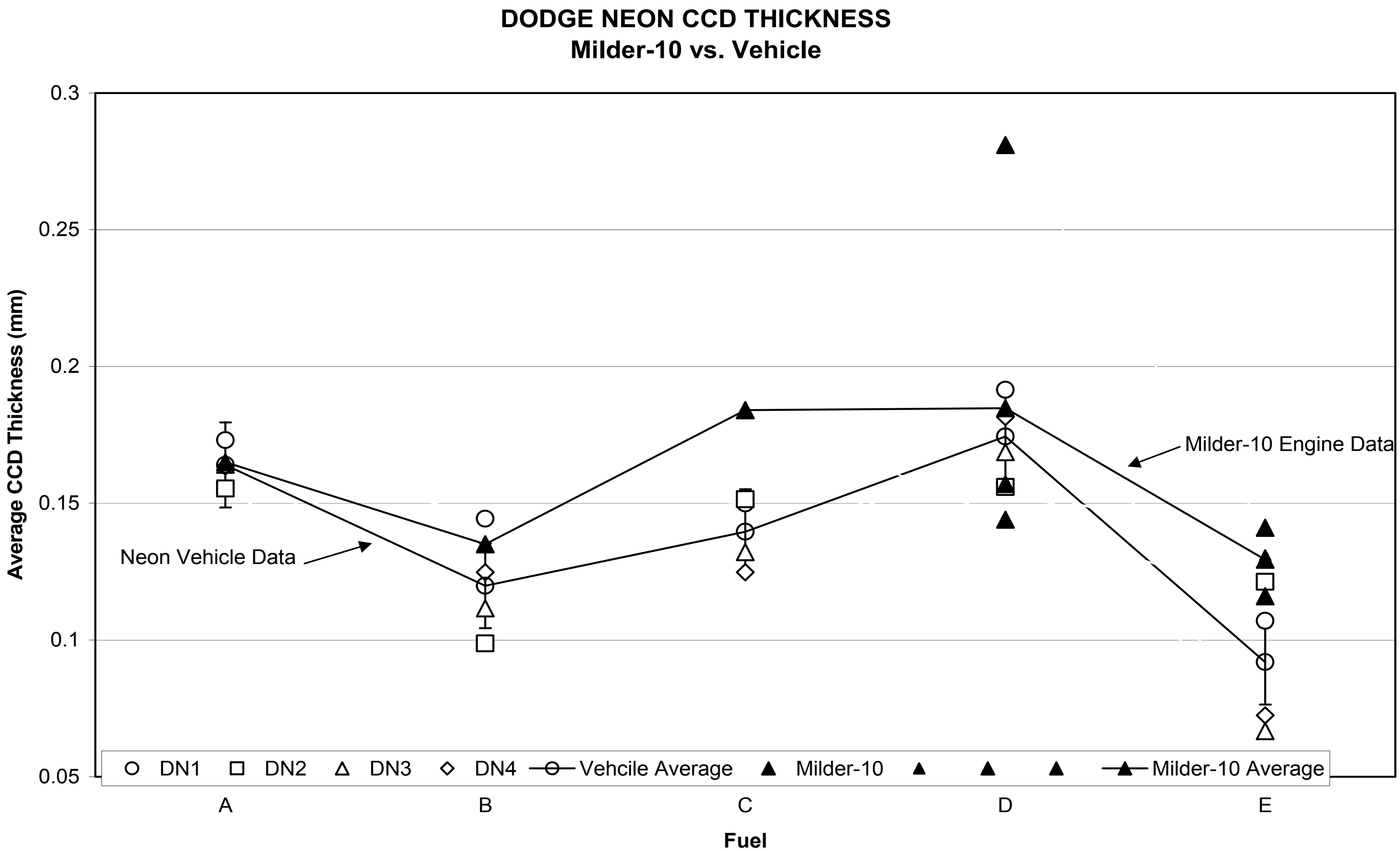
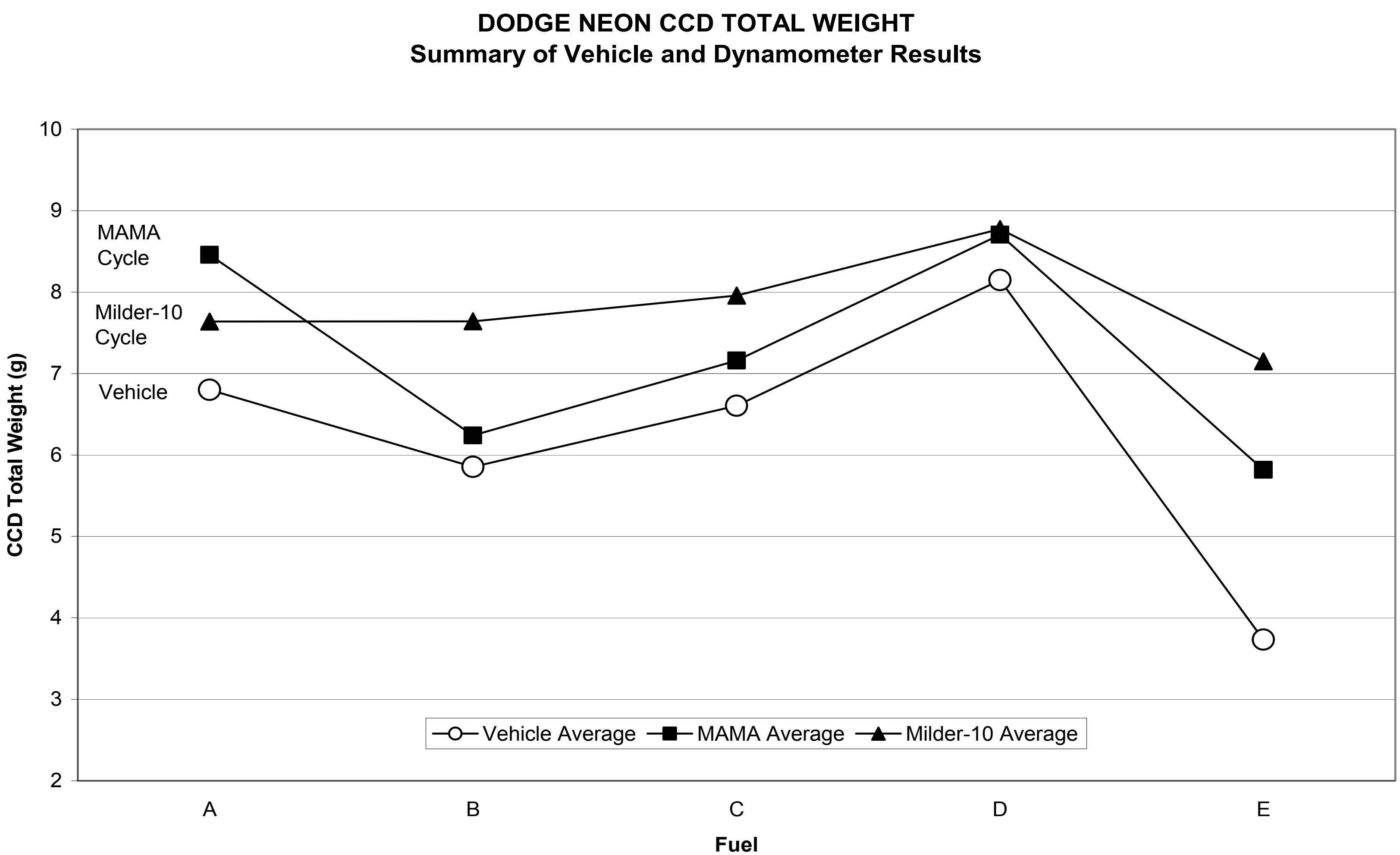

DODGE NEON CCD THICKNESS
Milder-10 vs. Vehicle
Average CCD Thickness (mm)
0.3
0.25
0.2
0.15
0.1
0.05
Neon Vehicle Data
Milder-10 Engine Data
DN1
DN2
DN3
DN4
Vehcile Average
Milder-10
Milder-10 Average
A
B
C
D
E
Fuel

Figure 30



DODGE NEON CCD TOTAL WEIGHT
Summary of Vehicle and Dynamometer Results
10
9
8
7
6
5
4
3
2
MAMA
Cycle
Milder-10
Cycle
Vehicle
CCD Total Weight (g)
Vehicle Average
MAMA Average
Milder-10 Average
A
B
C
D
E
Fuel

Figure 31

VEHICLE CCD TOTAL WEIGHT vs. UNWASHED GUM

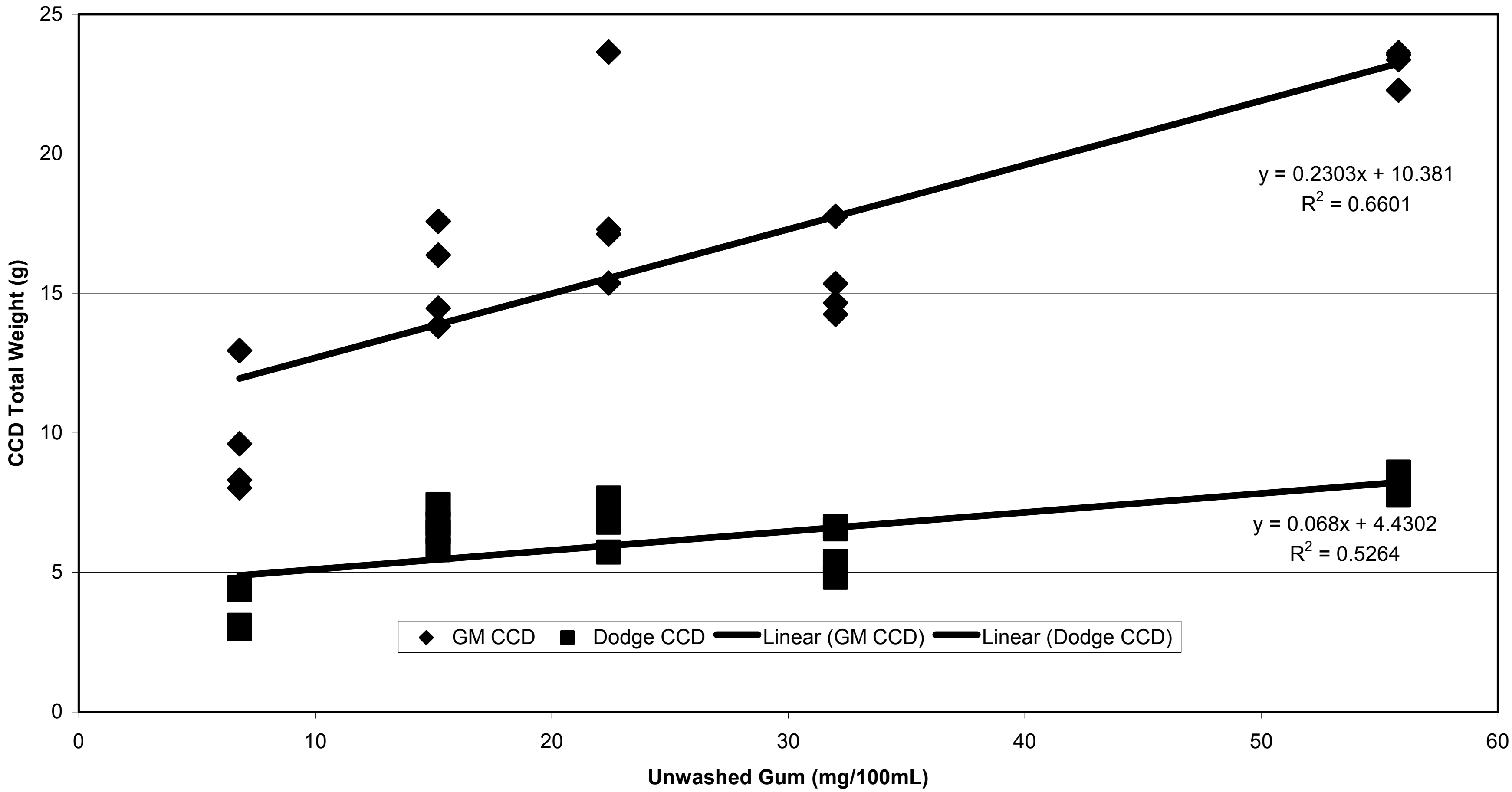


Figure 32

COMPARISON OF FUELS IN TGA TEST

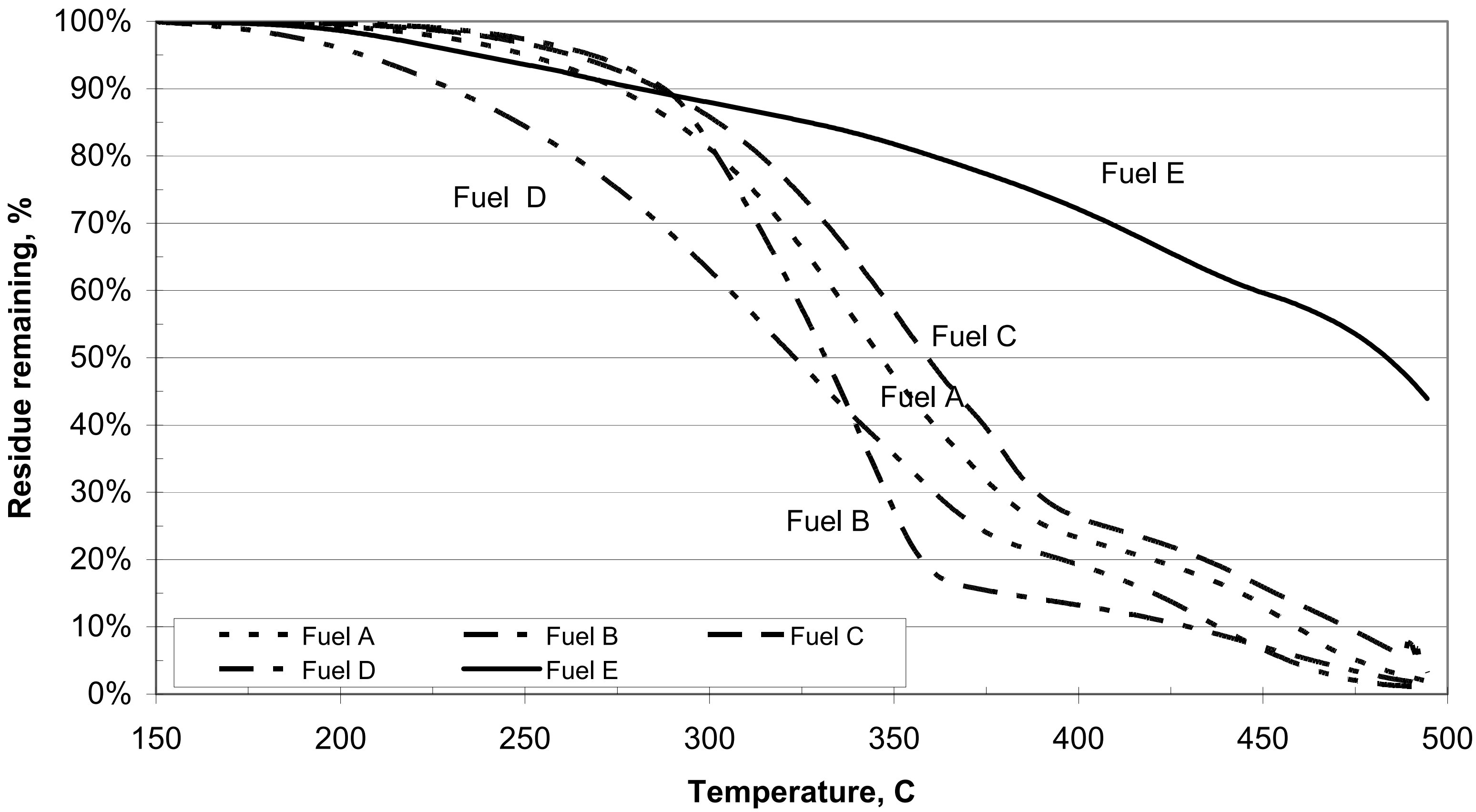


Figure 33

TGA GASOLINE GUM

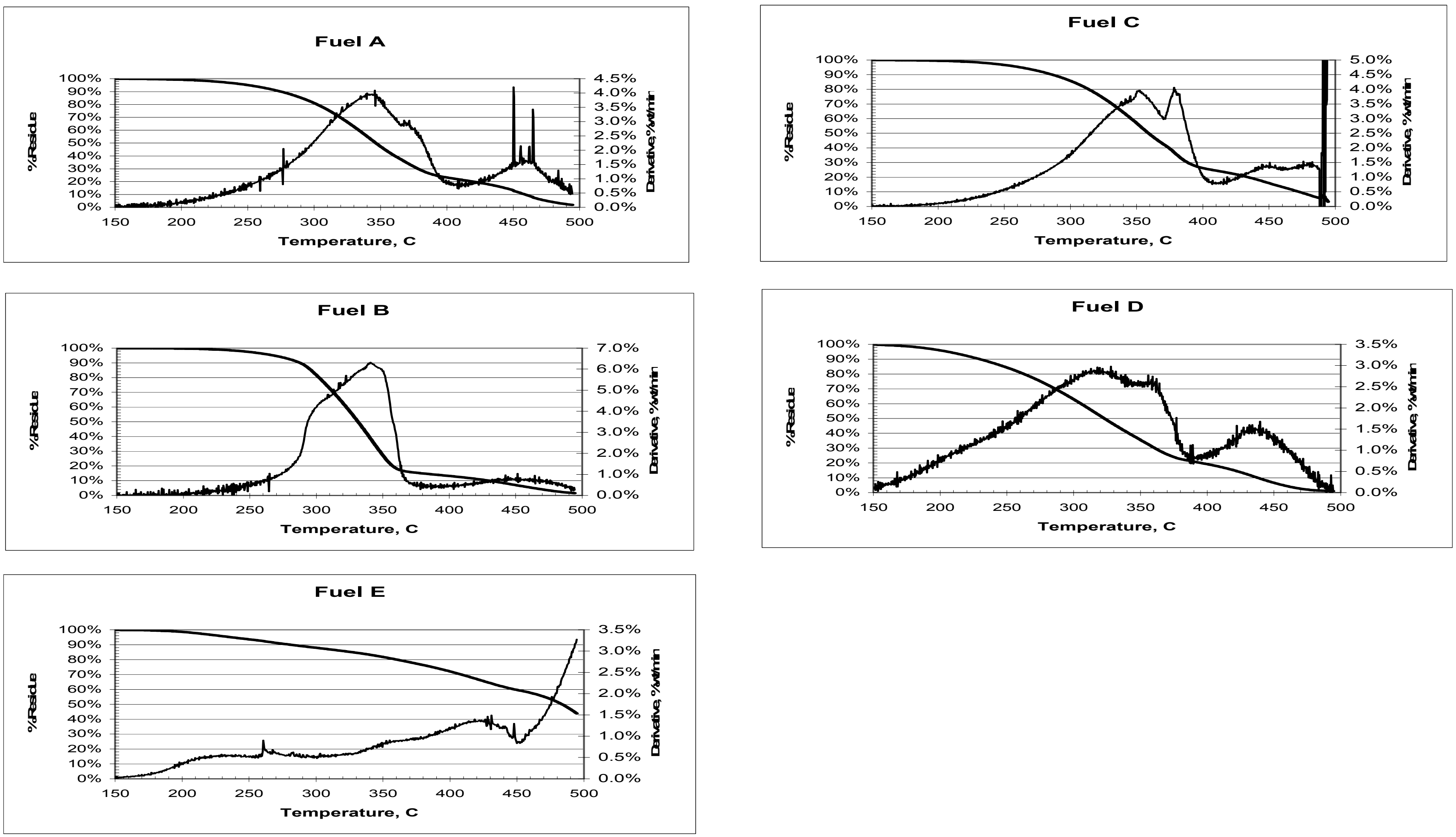


Figure 34

RELATIONSHIP OF TGA AND CCD IN CHEVROLET SILVERADO VEHICLE TESTS

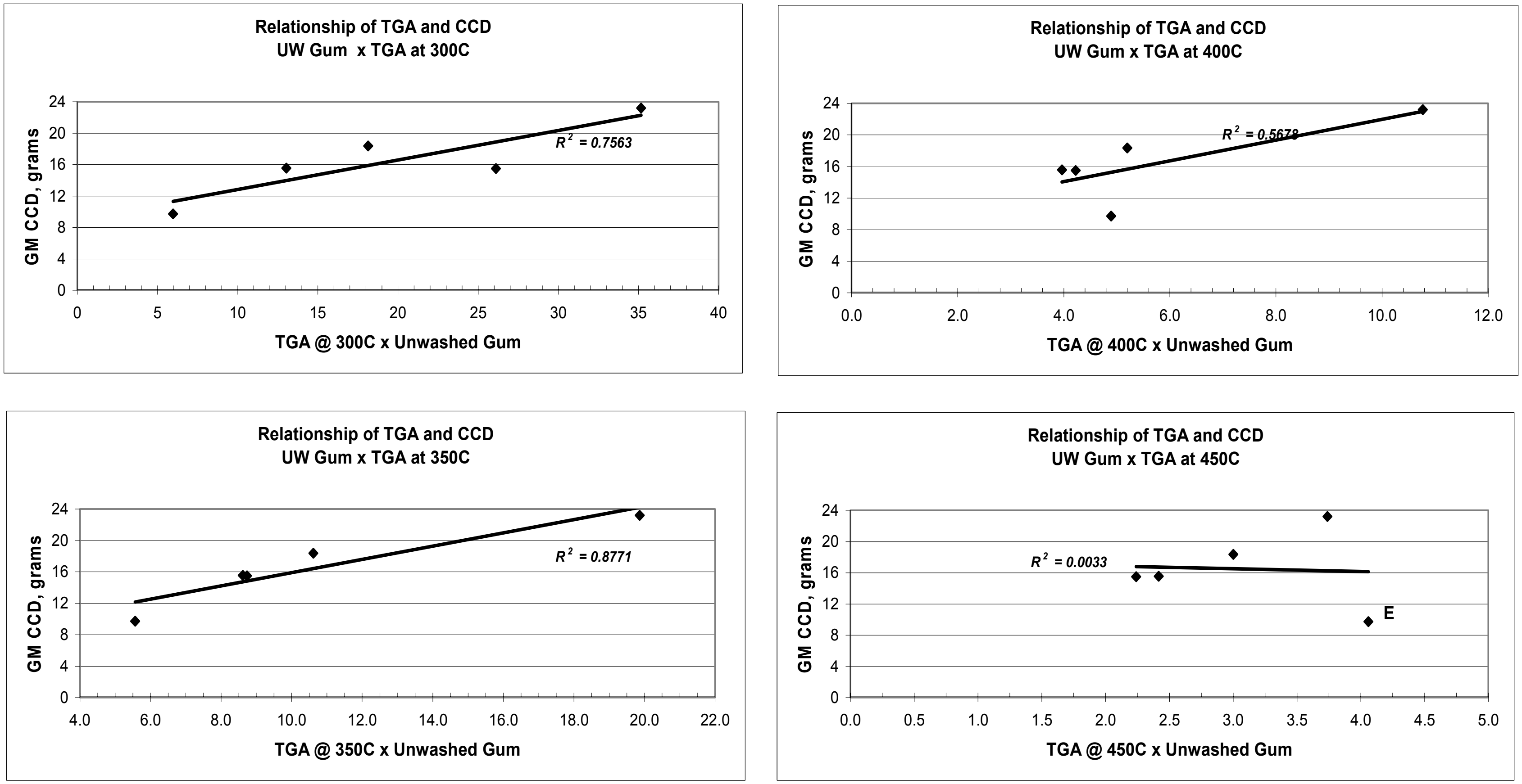


Figure 35

RELATIONSHIP OF TGA AND CCD IN DODGE NEON VEHICLE TESTS

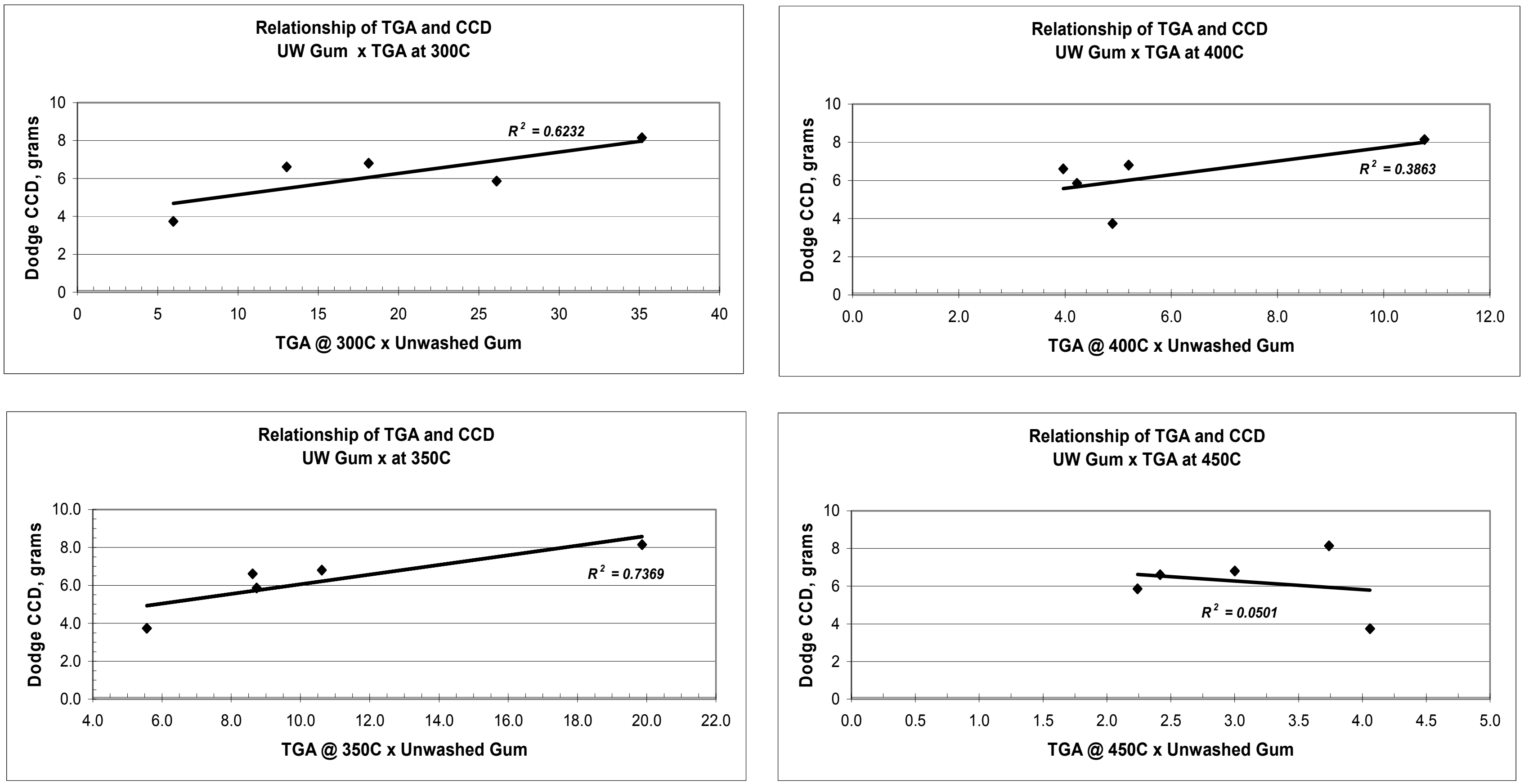


Figure 36

RELATIONSHIP OF TGA AND COMBINED AVERAGE CCD IN VEHICLE TESTS

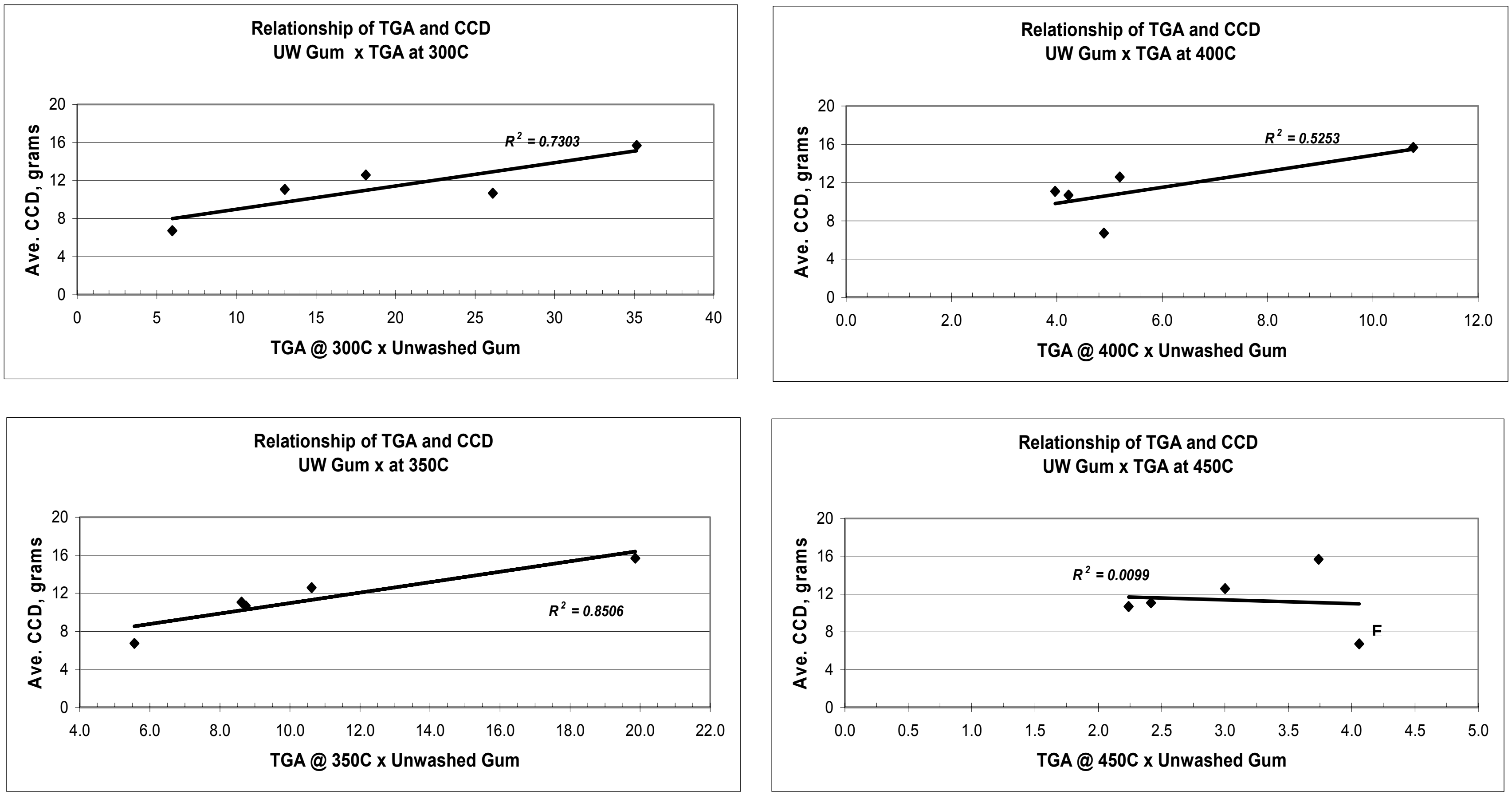


Figure 37

TGA RELATIONSHIP TO CCD
ALL FUELS

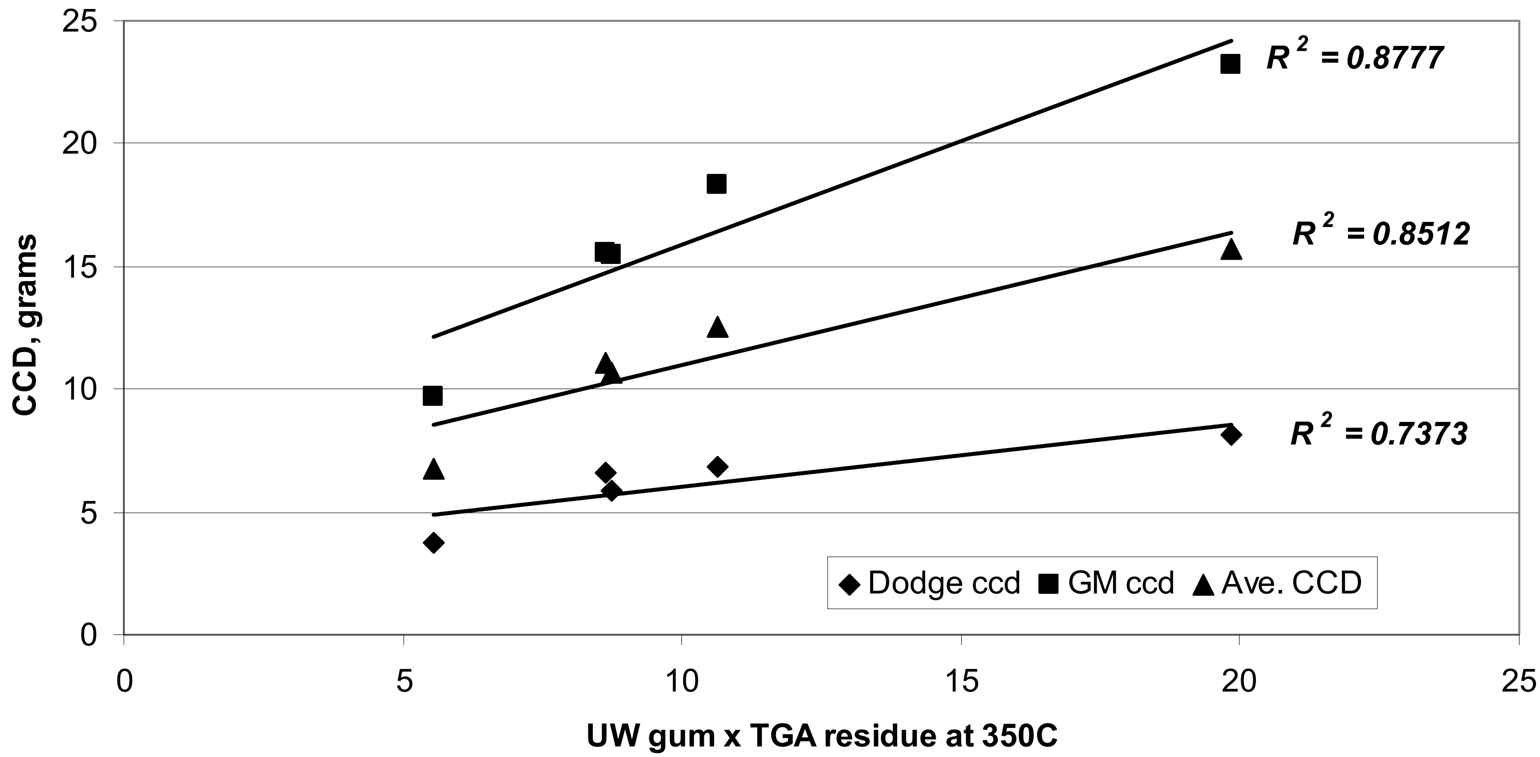


Figure 38

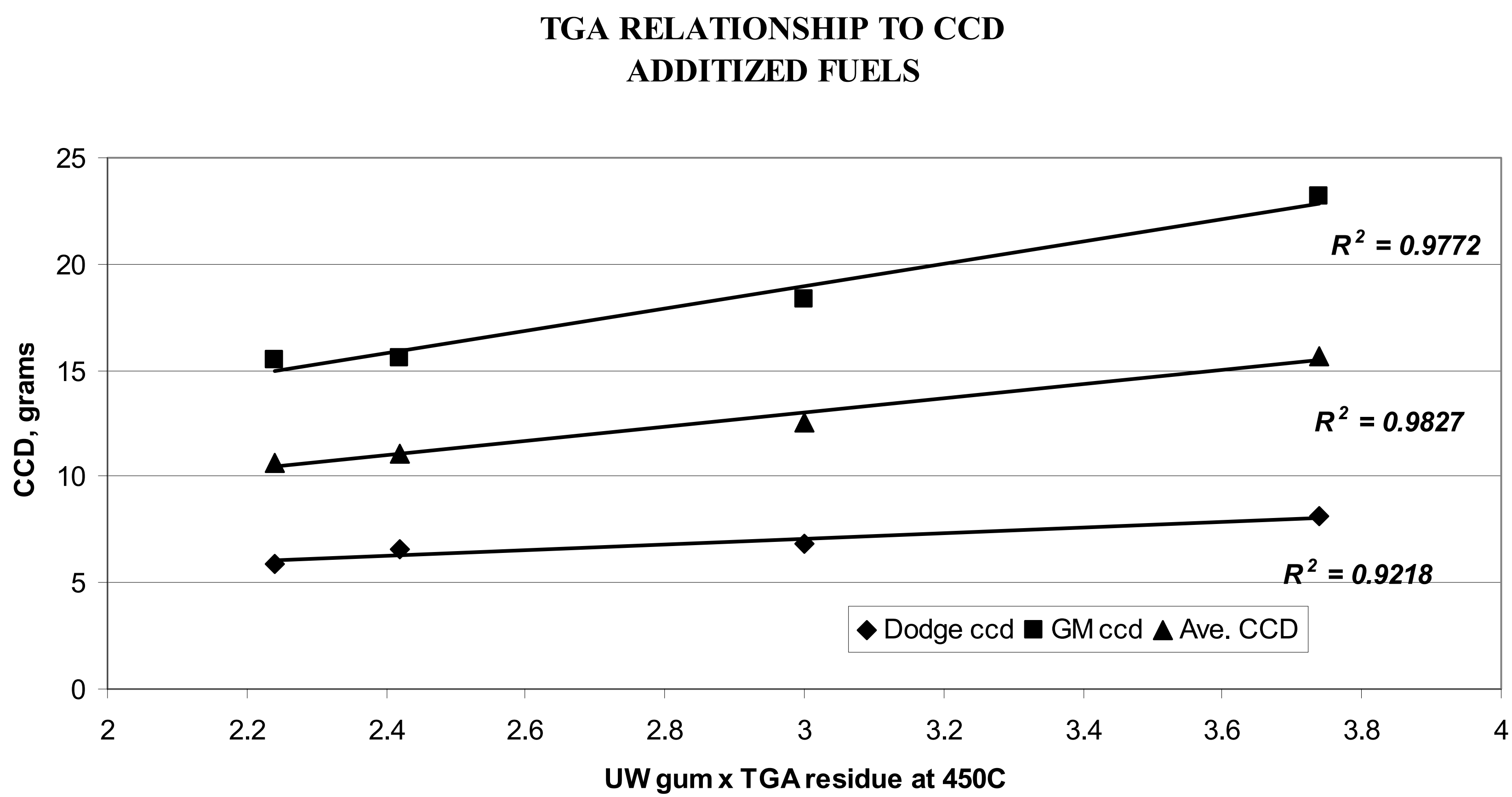

TGA RELATIONSHIP TO CCD
ADDITIZED FUELS
25
20
15
10
5
0
CCD, grams
2
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8
4
UW gum x TGA residue at 450C
R 2 = 0.9772
R 2 = 0.9827
R 2 = 0.9218
Dodge ccd
GM ccd
Ave. CCD

Figure 39

2-VARIABLE REGRESSION FOR GM SILVERADO CCD
Silverado CCD = 8.50 +1.60 Gum*T350C -1.57Gum*T400C

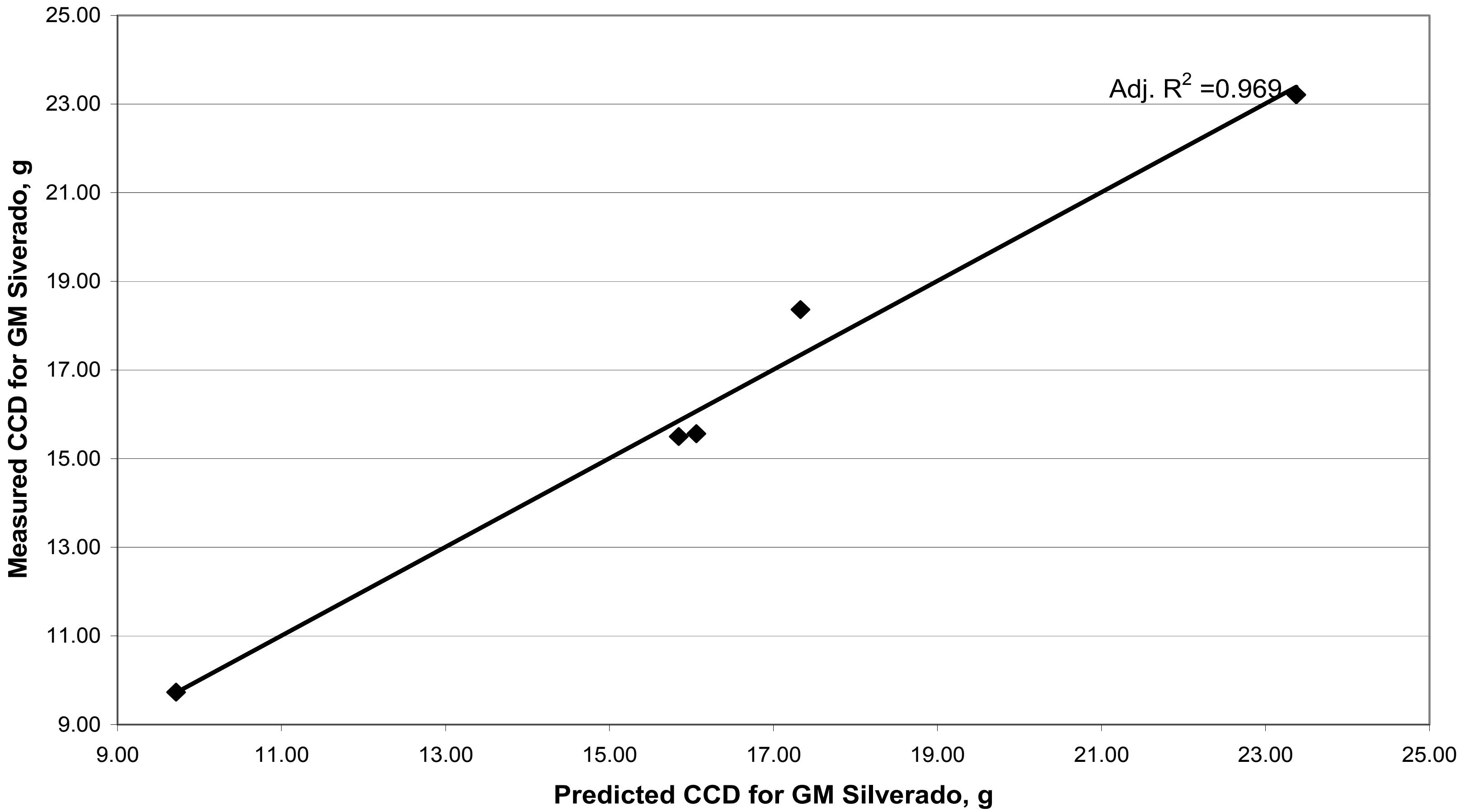


Figure 40

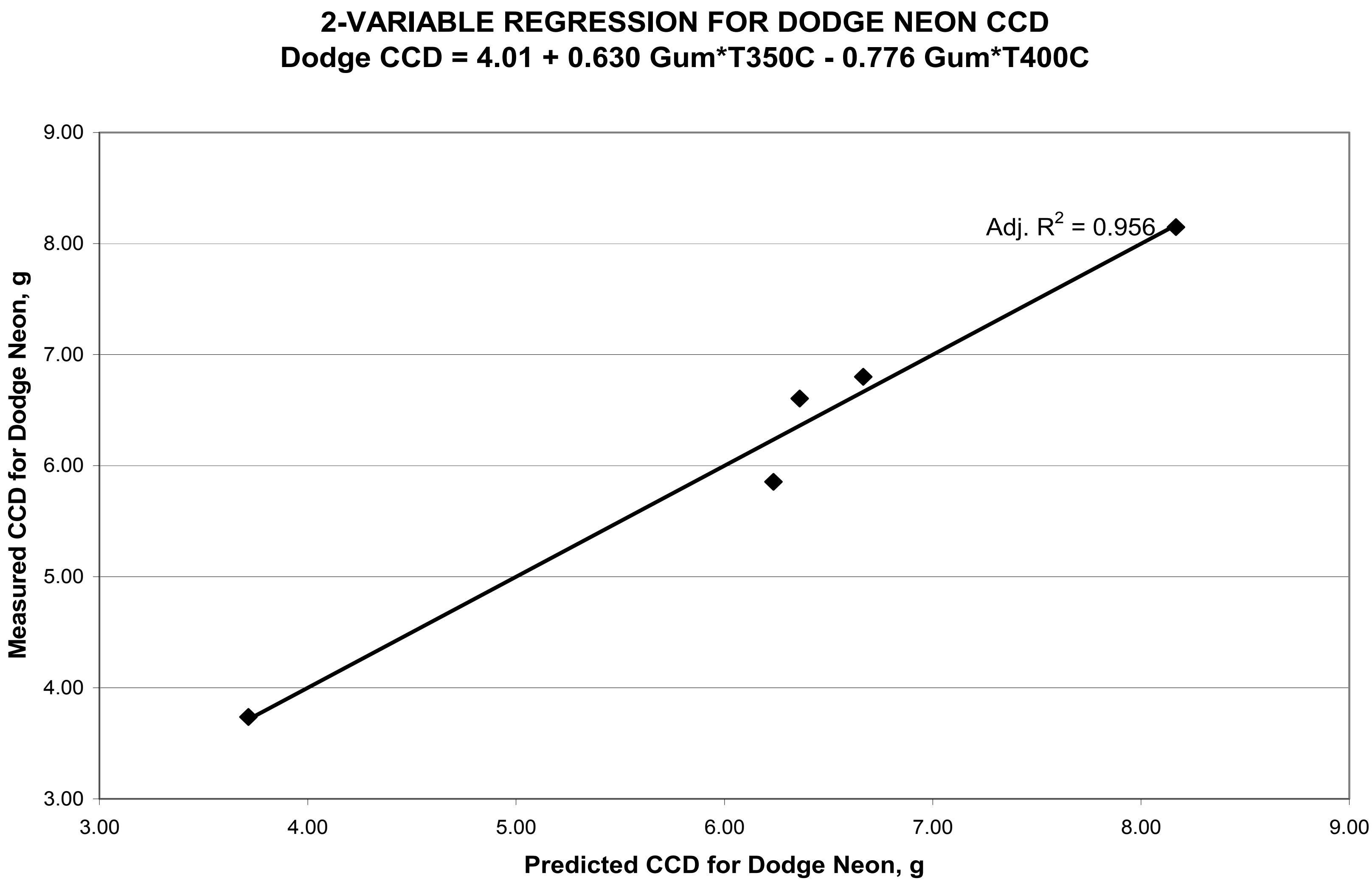

2-VARIABLE REGRESSION FOR DODGE NEON CCD
Dodge CCD = 4.01 + 0.630 Gum*T350C - 0.776 Gum*T400C
Adj. R2 = 0.956
Measured CCD for Dodge Neon, g
Predicted CCD for Dodge Neon, g
3.00
4.00
5.00
6.00
7.00
8.00
9.00

Figure 41

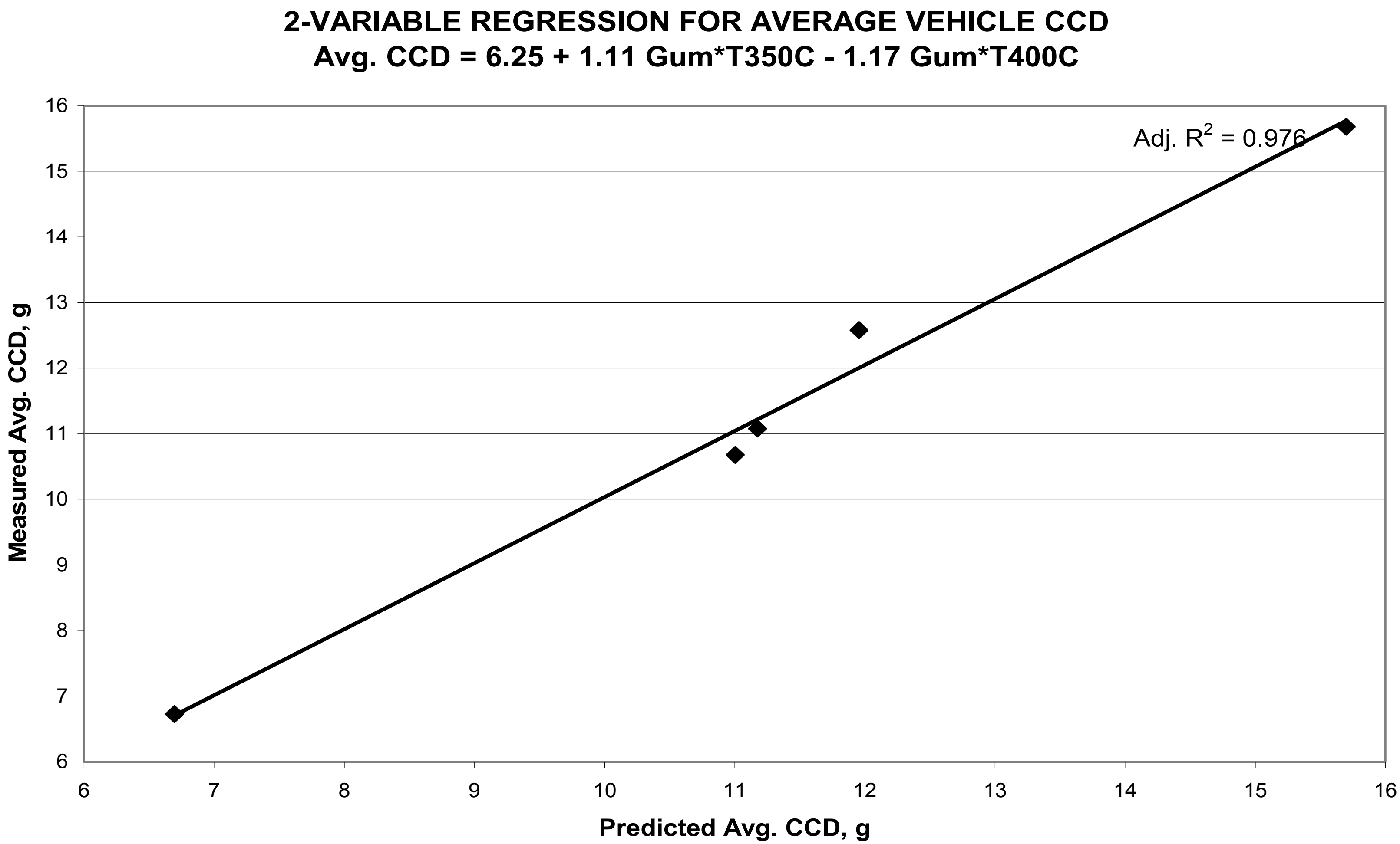

2-VARIABLE REGRESSION FOR AVERAGE VEHICLE CCD
Avg. CCD = 6.25 + 1.11 Gum*T350C - 1.17 Gum*T400C
Adj. R^2 = 0.976
Measured Avg. CCD, g
Predicted Avg. CCD, g
6
7
8
9
10
11
12
13
14
15
16

Figure 42

INDIVIDUAL CCD TOTAL WEIGHT DATA vs. TGA@350C x UNWGUM
ALL FUELS

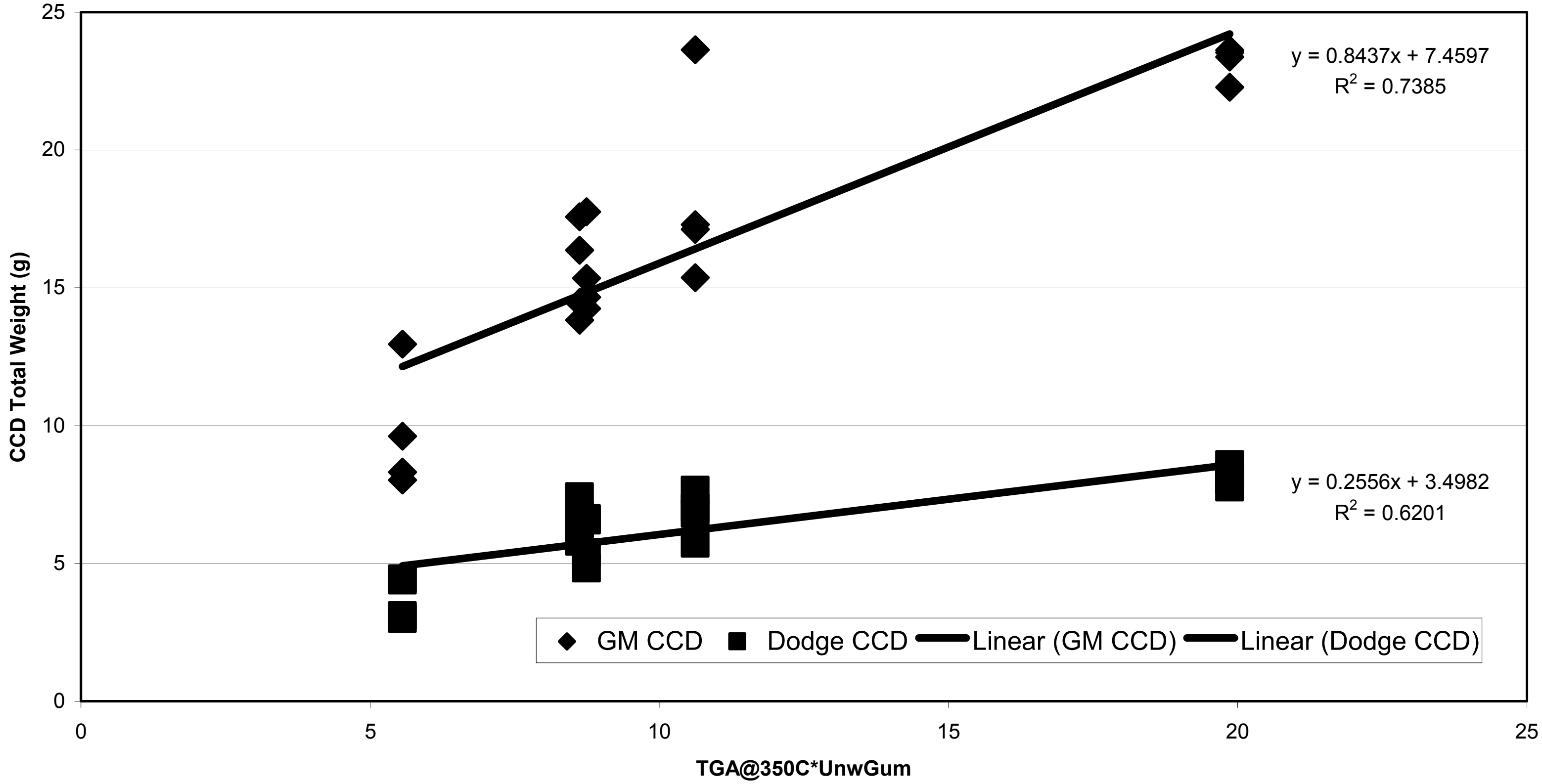


Figure 43

INDIVIDUAL CCD TOTAL WEIGHT DATA vs. TGA@450 x UNWGUM
ADDITIZED FUELS ONLY

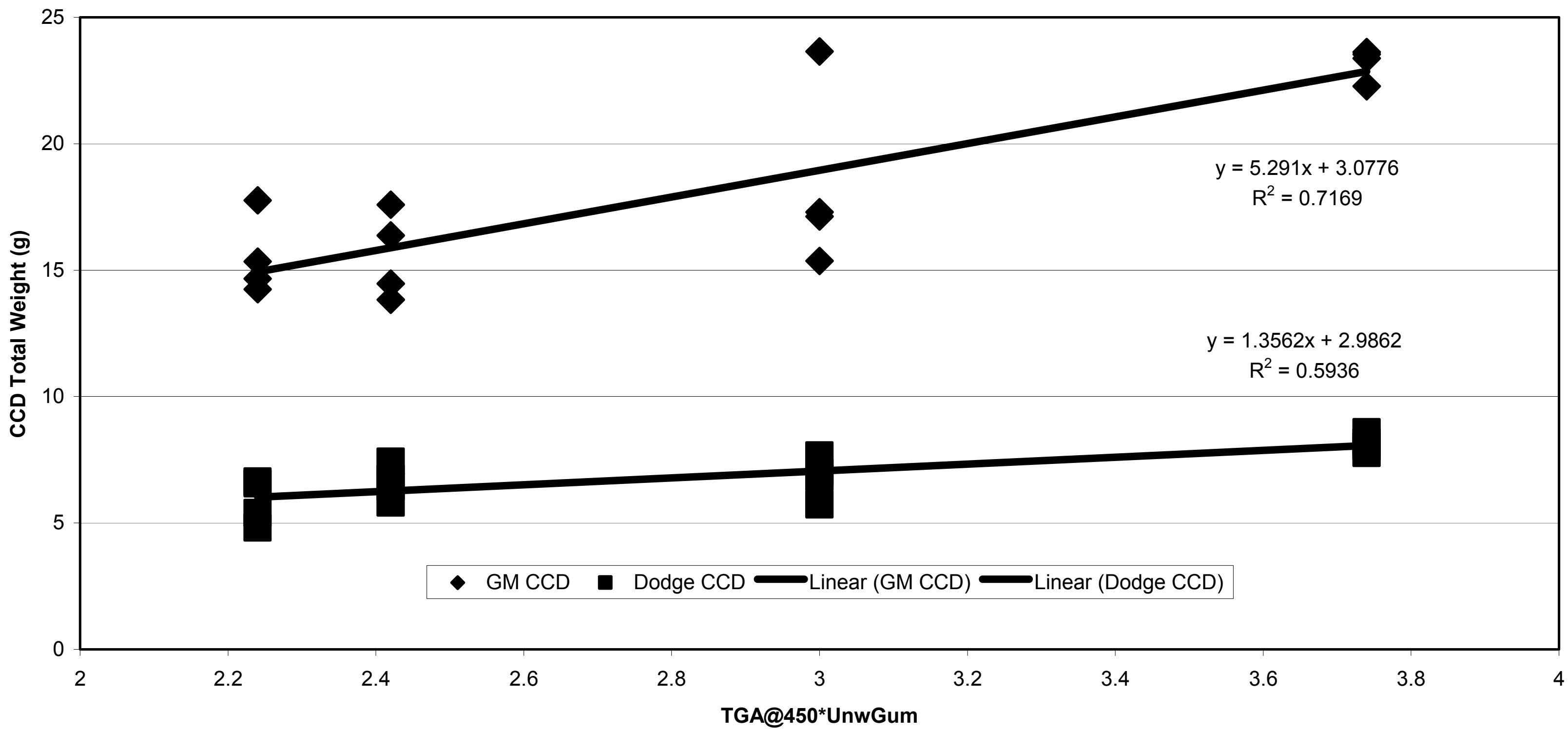


Figure 44

APPENDIX A

MEMBERSHIP OF THE

CRC COMBUSTION CHAMBER DEPOSIT

PROGRAM PANEL

MEMBERSHIP OF THE CRC COMBUSTION CHAMBER DEPOSIT PROGRAM PANEL

Member	Affiliation
Majid Ahmadi	Chevron Oronite Company
N. L. (Toby) Avery	ExxonMobil Research & Engineering
Loren Beard	DaimlerChrysler Corporation
Andy Buczynsky	General Motors Corporation
Beth Evans	Evans Research Consultants
Lew Gibbs	ChevronTexaco Products Company
Joe Joseph	BP Oil Company
Alex Kulinowski	Ethyl Petroleum Additives
Bill Most	Fuel Technology Associates
Chuck Richardson	Ford Motor Company
Jim Rutherford	Chevron Oronite Company
M. E. (Woody) Woodyard	Shell Global Solutions (US)

APPENDIX B

PROJECT DESCRIPTION OF THE CRC COMBUSTION CHAMBER DEPOSIT TEST DEVELOPMENT PROGRAM

CRC Project Description

Title:
Combustion Chamber Deposit (CCD) Test Development

Project Objective:
This project is intended as the key step towards developing an engine test procedure to use as a "research tool" for evaluation of combustion chamber deposits. Objectives include:

1) Identify an engine/cycle/duration or analytical/bench test
2) Verify additive rankings versus vehicles on the road in various base fuels

Project Background:
Three related CRC test programs (Emissions, Parametric, and Validation Studies) have generated data relating to CCD effects on emissions and on the effects of engine operating conditions on CCD levels. This project will build on those programs to develop a CCD test procedure based on a dyno engine test and may provide initial data leading to development of a CCD analytical/bench test.

Project Approach:
Test Design: Base fuel and four additized gasolines will be tested using two engine models on dyno stands and in vehicles, and in several analytical/bench tests to generate data that compares dyno stand and bench test results to vehicles on the road. Additives will include the high CCD additive from the Emissions Study and three commercial additives. Two dyno engine makes will be operated on two different operating cycles, making a total of four engine test protocols. The vehicles will all be operated on only one cycle. Each test condition will be replicated four times to provide statistical significance, resulting in the following test design:

Table 1. Number of Tests at Each Condition

	Dynamometer Test Stand				Vehicles	
	Ford 2.3L		Neon 2.0L		Ford 2.3L	Neon 2.0L
	Low Cycle	High Cycle	Low Cycle	High Cycle	Modified AAMA	Modified AAMA
Base fuel	4	4	4	4	4	4
Additive A	4	4	4	4	4	4
Additive B	4	4	4	4	4	4
Additive C	4	4	4	4	4	4
Emissions additive	4	4	4	4	4	4
Total no. of tests	20	20	20	20	20	20

Total dyno tests are 80 and total vehicle tests are 40. Each dyno engine block will be run for ten 300-hour tests, requiring four blocks of each engine type. Each of the vehicles will be run for a four thousand mile break-in, followed by five successive 15,000-mile tests. The cylinder heads and piston tops will be cleaned after each test. IVD mass, CCD mass, and CCD thickness will be measured, along with CRC ratings of intake valves, intake ports and runners.

Engines/Vehicles: GM 6.0L Generation III and Dodge Neon 2.0L SOHC engines will be tested. Vehicles will be 1999 GM pickups and 1999 Dodge Neons. Two engine stands of each type must be run simultaneously to meet project timing requirements. Four vehicles of each type will be required, all to be run simultaneously. Vehicles are to be new, and will be obtained by the test laboratory. Engines for dyno testing will be supplied by CRC or the OEMs, but the test laboratory will have to set up the engine stand using technical support from the respective OEM. Each engine and vehicle will be broken in prior to test start, consisting of 100 hours on cycle for the dyno engine and 4000 miles for the vehicles.

Fuel/Additives: Base fuel for all testing will be RF-A. Five fuels will be tested, the RF-A base fuel as one and the other four consisting of three commercial additives and the high CCD additive used in the CRC Emissions Program. The three commercial additives will be chosen blindly by the test lab from a selection of additives supplied by major oil companies. The additives will be classed into the following groups, and one chosen from each group:

1) Premium dose polyetheramine
2) Premium dose PIBA with synthetic carrier fluid
3) Regular dose (LAC) PIBA with synthetic carrier fluid

Test Cycles: Dyno engines will be run on two different cycles, each 300 hours duration. Cycles will be modified versions of the MAMA driving cycle used in the Emissions Study. One will utilize lower speeds and loads than the other. Tests in vehicles will be 15,000 miles, using the modified MAMA cycle from the CRC Emissions Study. Engine tests will run continuously, but a minimum 8-hour daily soak will be included with the vehicle tests.

Emissions Testing: Emissions testing of the eight vehicles is an option. Such testing would consist of duplicate FTP emissions tests on each vehicle at start of test, at end of 15,000 miles, and after engine reassembly clean. Cost and timing impact for emissions testing will be requested from labs bidding on the project.

<u>Project Deliverables:</u>

The project will provide information that assists in selection of an engine test protocol that can 1) detect CCD differences between additives of different CCD contribution levels and 2) rank additives in the same relative order as in vehicles operated on the road.

In addition, promising analytical/bench tests may be identified that with further development could serve as a method to evaluate CCD forming tendencies of gasoline additives.

Project Timing:
It is anticipated that approximately one and one-half years will be required to complete testing and analyze results.

III. Executive Summary
CRC CCD Test Development Program

The CRC Performance Committee in its August 1997 meeting decided to proceed with development of an engine test as a "research tool" to measure combustion chamber deposits. A test proposal developed by representatives of the Performance and Emissions committees that attended the November 20th CCD meeting in Chicago is described below. While this program is primarily intended to lead towards development of a CCD engine test, there is also value in the information generated regarding the effects of additives on CCD levels.

The test program will consist of 80 engine dynamometer tests and 40 vehicle tests, using two vehicle/engine models and five fuels, with 4 repeats on each combination. For the dynamometer tests, each engine will be evaluated using two different test cycles, all of 300 hours duration. The engine/vehicle types are a Ford 2.3/2.5L Ranger pickup and a Chrysler Neon 2.0L. These engines were chosen because of favorable response to fuels or test condition changes, industry experience using them on dynamometers, and available factory support.

Five fuels will be tested, all using the same RFA base fuel (but a different batch) as used in the Emissions Study. Fuels will include: 1) Base fuel alone, 2) The high CCD additive from the Emissions Study, and 3) Three representative commercial additive packages obtained from oil companies. In order to obtain cooperation of the oil and additive companies, the companies and their additive types and dosages will be coded and will NOT be revealed. These additives will be:

1) A polyether amine at a dose used in premium gasoline
2) A PIBA/synthetic carrier at a dose used in premium gasoline
3) A PIBA/synthetic carrier at a very low dose intended to barely meet requirements.

Inclusion of commercial additives with one additive from the Emissions study will also provide information as to how the additives tested in the Emissions study compare with typical additive packages now in use.

Using this approach, the probability of success for showing CCD differences between base fuel and additized fuels as a group is high. Only about a 20% difference is required to have a good chance of demonstrating a statistically significant difference. However, differences between individual fuels are not expected to be statistically significant unless the real difference is over 50%, which is considered unlikely to occur between the commercial additives. There is a moderate probability that the high CCD additive will be statistically worse than the commercial additives. Thus, an overall result with at least three levels of CCD performance is a likely possibility, allowing for verifying rank order of the additives between bench test, engine test, and vehicles on the road.

Results from this program will be used to choose an engine and test cycle for use in a CCD test procedure. After selection, additional test work would be required in that engine and cycle to verify that additive ranking is proper in other base fuels, such as RFG or California Phase II gasolines. This would be a much smaller effort, in that only one test protocol would be involved, and fewer additives could be chosen basis the results of this program.

APPENDIX C

FINAL REPORT OF

PERKIN ELMER AUTOMOTIVE RESEARCH

ON THE ENGINE DYNAMOMETER PHASE

May 06, 2004

A report on:

COMBUSTION CHAMBER DEPOSIT TEST DEVELOPMENT PROGRAM - DYNAMOMETER EVALUATION

In response to:
CRC Project No. CM-136-98/CCD-3

Prepared for:

Coordinating Research Council, Inc.
3650 Mansell Road, Suite 140
Alpharetta, Georgia 30022-8246

Attention: Mr. Timothy C. Belian, Executive Director

Prepared by: Dan Worcester, Senior Project Engineer

Approved:

Brad Carter
Director
Crankcase Lubricants Testing Department
PerkinElmer Automotive Research

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I. INTRODUCTION

The Coordinating Research Council requested bids to develop a research tool using an engine dynamometer or analytical/bench test. This program was designed to determine the relative ranking of combustion chamber deposits (**CCD**) for a variety of fuel additives and a known base fuel for the dynamometer tests and the vehicles. PerkinElmer Automotive Research (**PEAR**) performed the engine dynamometer portion of this program. Five fuels, two engine configurations, and two test cycles were selected for the original program. Additional cycles were developed later in testing.

There were two objectives. The first was to program a computer to run both the Modified Alternate Mileage Accumulation (**MAMA**) vehicle cycle on an engine dynamometer, and a second cycle that would be easier to program and share with other labs (called the SIMPLE cycle because it was easier to program). The second goal was to verify fuel additive rankings versus the vehicles run on those same additives.

II. BACKGROUND

Certain gasoline spark-ignition engine designs have been susceptible to performance problems due to blockage from intake valve deposits (**IVD**). Fuels have been modified to work more efficiently with newer injection systems, and to reduce emissions from the entire vehicle. Fuel additives had been developed to reduce IVD, but these can move deposits to the combustion chambers. Changes in emissions regulations, customer needs, and production requirements made several new engine designs very susceptible to mechanical interference between the pistons and cylinder head(s) (**CCD knock**), especially during cold starts. This CCD knock problem initiated much of the early CCD testing. Recent research efforts have been to find a tool focused on finding a tool to evaluate CCD formation in modern engine designs.

This program builds on previous testing, and has two segments – testing on vehicles, then running the same engines on a dynamometer. Two vehicle/engine combinations were selected. They were a DaimlerChrysler (**DC**) Neon with a 2.0 litre transverse mounted in-line 4-cylinder engine, and a General Motors (**GM**) 2500 series truck with a 6.0 litre rear drive V-8 engine. The additives consisted of two premium dose commercial packages, a commercial package at the LAC dosage level, and a high CCD package used in an earlier test program. RF-A was selected as a known base fuel.

For dynamometer testing, two Neon and two Chevrolet engines were installed. All engines ran both dynamometer test cycle. Operating conditions for both cycles were developed from collected vehicle data. Tables 1 through 6 show the stage, times, and engine (**RPM**) and throttle position [**TPS for throttle position sensor, or % wide open throttle (%WOT)]** values for each steady state condition for each engine type.

TABLE 1: MAMA CYCLE

STAGE	MPH	TIME	GM	GM	DC	DC
		seconds	RPM	TPS(%WOT)	RPM	TPS(%WOT)
IDLE	0	120	750	2.500	800	1.500
RAMP UP	-	6	3000	40	3000	60
HOLD	-	9	3000	40	3000	60
1	30	120	1400	7.503	1600	5.794
RAMP DN	-	6	750	2.500	800	1.500
IDLE	0	100	750	2.500	800	1.500
RAMP UP	-	6	3000	40	3000	60
HOLD	-	18	3000	40	3000	60
2 to 9	60	75	1900	18.907	2700	13.915
RAMP DN	-	6	750	2.500	800	1.500
IDLE	0	15	750	2.500	800	1.500
REPEAT	THIS	SET	8	TIMES		
RAMP UP	-	6	3000	40	3000	60
HOLD	-	21	3000	40	3000	60
10, 11	70	900	2200	25.020	3100	18.765
RAMP DN	-	6	750	2.500	800	1.500
IDLE	0	45	750	2.500	800	1.500
REPEAT	THIS	SET	2	TIMES		
RAMP UP	-	6	3000	40	3000	60
HOLD	-	18	3000	40	3000	60
12	55	200	1700	17.396	2400	12.092
RAMP DN	-	6	750	2.500	800	1.500
IDLE	0	120	750	2.500	800	1.500
RAMP UP	-	6	3000	40	3000	60
HOLD	-	9	3000	40	3000	60
13 to 45	30	45	1400	7.503	1600	5.794
RAMP DN	-	6	750	2.500	800	1.500
14 to 46	10	10	1000	3.403	1000	3.403
RAMP DN	-	6	750	2.500	800	1.500
REPEAT	THIS	SET	11	TIMES		
RAMP UP	-	6	3000	40	3000	60
HOLD	-	12	3000	40	3000	60
47 to 56	40	20	1700	11.175	1800	7.636
RAMP DN	-	6	750	2.500	800	1.500
48 to 57	20	20	1100	4.347	1100	3.700
RAMP DN	-	6	750	2.500	800	1.500
REPEAT	THIS	SET	5	TIMES		
IDLE	0	20	750	2.500	800	1.500
RAMP UP	-	6	3000	40	3000	60
HOLD	-	18	3000	40	3000	60
58	55	180	1700	17.396	2400	12.092
RAMP DN	-	6	750	2.500	800	1.500
IDLE	0	240	750	2.500	800	1.500
RAMP UP	-	6	3000	40	3000	60
HOLD	-	18	3000	40	3000	60
59	60	510	1900	18.907	2700	13.915
RAMP DN	-	6	750	2.500	800	1.500
IDLE	0	20	750	2.500	800	1.500
RAMP UP	-	6	3000	40	3000	60
HOLD	-	18	3000	40	3000	60
60	55	510	1700	17.396	2400	12.092
RAMP DN	-	6	750	2.500	800	1.500
IDLE	0	30	750	2.500	800	1.500
RUN	**12**	**2**	**HOUR**	**CYCLES**	**EACH**	**DAY**
CHANGE	**OIL**	**AT**	**100**	**AND**	**200**	**HOURS**

TABLE 2: MAMA CYCLE WITH DAILY 8 HOUR SOAKS

STAGE	MPH	TIME	GM	GM	DC	DC
		seconds	RPM	TPS(%WOT)	RPM	TPS(%WOT)
IDLE	0	120	750	2.500	800	1.500
RAMP UP	-	6	3000	40	3000	60
HOLD	-	9	3000	40	3000	60
1	30	120	1400	7.503	1600	5.794
RAMP DN	-	6	750	2.500	800	1.500
IDLE	0	100	750	2.500	800	1.500
RAMP UP	-	6	3000	40	3000	60
HOLD	-	18	3000	40	3000	60
2 to 9	60	75	1900	18.907	2700	13.915
RAMP DN	-	6	750	2.500	800	1.500
IDLE	0	15	750	2.500	800	1.500
REPEAT	THIS	SET	8	TIMES		
RAMP UP	-	6	3000	40	3000	60
HOLD	-	21	3000	40	3000	60
10, 11	70	900	2200	25.020	3100	18.765
RAMP DN	-	6	750	2.500	800	1.500
IDLE	0	45	750	2.500	800	1.500
REPEAT	THIS	SET	2	TIMES		
RAMP UP	-	6	3000	40	3000	60
HOLD	-	18	3000	40	3000	60
12	55	200	1700	17.396	2400	12.092
RAMP DN	-	6	750	2.500	800	1.500
IDLE	0	120	750	2.500	800	1.500
RAMP UP	-	6	3000	40	3000	60
HOLD	-	9	3000	40	3000	60
13 to 45	30	45	1400	7.503	1600	5.794
RAMP DN	-	6	750	2.500	800	1.500
14 to 46	10	10	1000	3.403	1000	3.403
RAMP DN	-	6	750	2.500	800	1.500
REPEAT	THIS	SET	11	TIMES		
RAMP UP	-	6	3000	40	3000	60
HOLD	-	12	3000	40	3000	60
47 to 56	40	20	1700	11.175	1800	7.636
RAMP DN	-	6	750	2.500	800	1.500
48 to 57	20	20	1100	4.347	1100	3.700
RAMP DN	-	6	750	2.500	800	1.500
REPEAT	THIS	SET	5	TIMES		
IDLE	0	20	750	2.500	800	1.500
RAMP UP	-	6	3000	40	3000	60
HOLD	-	18	3000	40	3000	60
58	55	180	1700	17.396	2400	12.092
RAMP DN	-	6	750	2.500	800	1.500
IDLE	0	240	750	2.500	800	1.500
RAMP UP	-	6	3000	40	3000	60
HOLD	-	18	3000	40	3000	60
59	60	510	1900	18.907	2700	13.915
RAMP DN	-	6	750	2.500	800	1.500
IDLE	0	20	750	2.500	800	1.500
RAMP UP	-	6	3000	40	3000	60
HOLD	-	18	3000	40	3000	60
60	55	510	1700	17.396	2400	12.092
RAMP DN	-	6	750	2.500	800	1.500
IDLE	0	30	750	2.500	800	1.500
RUN	8	2	HOUR	CYCLES	EACH	DAY
SOAK	8	HOURS	EACH	DAY		
CHANGE	OIL	AT	100	AND	200	HOURS

TABLE 3: SIMPLE CYCLE

STAGE	MPH	TIME	GM	GM	DC	DC
	TPS	seconds	RPM	TPS(%WOT)	RPM	TPS(%WOT)
IDLE	0	120	750	2.500	800	1.500
RAMP UP	-	6	3000	40	3000	60
HOLD	-	9	3000	40	3000	60
1	30	120	1400	7.503	1600	5.794
RAMP DN	-	6	750	2.500	800	1.500
IDLE	0	240	750	2.500	800	1.500
RAMP UP	-	6	3000	40	3000	60
HOLD	-	18	3000	40	3000	60
2	60	180	1900	18.907	2700	13.915
RAMP DN	-	6	750	2.500	800	1.500
IDLE	0	240	750	2.500	800	1.500
RAMP UP	-	6	3000	40	3000	60
HOLD	-	21	3000	40	3000	60
3	70	180	2200	25.020	3100	18.765
RAMP DN	-	6	750	2.500	800	1.500
IDLE	0	20	750	2.500	800	1.500
RAMP UP	-	6	3000	40	3000	60
HOLD	-	12	3000	40	3000	60
4	30	120	1400	7.503	1600	5.794
RAMP DN	-	6	750	2.500	800	1.500
IDLE	0	20	750	2.500	800	1.500
RAMP UP	-	6	3000	40	3000	60
HOLD	-	9	3000	40	3000	60
5	30	120	1400	7.503	1600	5.794
RAMP DN	-	6	750	2.500	800	1.500
IDLE	0	20	750	2.500	800	1.500
RAMP UP	-	6	3000	40	3000	60
HOLD	-	9	3000	40	3000	60
6	40	120	1700	11.175	1800	7.636
RAMP DN	-	6	750	2.500	800	1.500
IDLE	0	20	750	2.500	800	1.500
RAMP UP	-	6	3000	40	3000	60
HOLD	-	12	3000	40	3000	60
7	40	860	1700	11.175	1800	7.636
RAMP DN	-	6	750	2.500	800	1.500
IDLE	0	30	750	2.500	800	1.500
RAMP UP	-	6	3000	40	3000	60
HOLD	-	9	3000	40	3000	60
8	30	900	1400	7.503	1600	5.794
RAMP DN	-	6	750	2.500	800	1.500
IDLE	0	30	750	2.500	800	1.500
THIS	IS	A	1	HOUR	CYCLE	
CHANGE	OIL	AT	100	AND	200	HOURS

TABLE 4: SIMPLE CYCLE WITH 15 SECOND RAMPS

STAGE	MPH	TIME	DC	DC
		seconds	RPM	TPS(%WOT)
IDLE	0	120	800	1.500
RAMP UP	-	15	1600	5.794
1	30	120	1600	5.794
RAMP DN	-	15	800	1.500
IDLE	0	240	800	1.500
RAMP UP	-	15	2700	13.915
2	60	180	2700	13.915
RAMP DN	-	15	800	1.500
IDLE	0	240	800	1.500
RAMP UP	-	15	3100	18.765
3	70	180	3100	18.765
RAMP DN	-	15	800	1.500
IDLE	0	20	800	1.500
RAMP UP	-	15	1600	5.794
4	30	120	1600	5.794
RAMP DN	-	15	800	1.500
IDLE	0	20	800	1.500
RAMP UP	-	15	1600	5.794
5	30	120	1600	5.794
RAMP DN	-	15	800	1.500
IDLE	0	20	800	1.500
RAMP UP	-	15	1800	7.636
6	40	120	1800	7.636
RAMP DN	-	15	800	1.500
IDLE	0	20	800	1.500
RAMP UP	-	15	1800	7.636
7	40	860	1800	7.636
RAMP DN	-	15	800	1.500
IDLE	0	15	800	1.500
RAMP UP	-	15	1600	5.794
8	30	900	1600	5.794
RAMP DN	-	15	800	1.500
IDLE	0	75	800	1.500
THIS	IS	1	HOUR	CYCLE

TABLE 5: MILDER CYCLE

STAGE	MPH	TIME	DC	DC
		seconds	RPM	TPS (%WOT)
IDLE	0	80	800	1.500
RAMP UP	-	6	3000	60
HOLD	-	9	3000	60
1	30	620	1600	5.794
RAMP DN	-	6	800	1.500
IDLE	0	80	800	1.500
RAMP UP	-	6	3000	60
HOLD	-	21	3000	60
2	70	620	3100	18.765
RAMP DN	-	6	800	1.500
IDLE	0	80	800	1.500
RAMP UP	-	6	3000	60
HOLD	-	9	3000	60
3	30	620	1600	5.794
RAMP DN	-	6	800	1.500
IDLE	0	80	800	1.500
RAMP UP	-	6	3000	60
HOLD	-	12	3000	60
4	40	620	1800	7.636
RAMP DN	-	6	800	1.500
IDLE	0	80	800	1.500
RAMP UP	-	6	3000	60
HOLD	-	9	3000	60
5	30	620	1600	5.794
RAMP DN	-	6	800	1.500
IDLE	0	80	800	1.500
THIS	IS	1	HOUR	CYCLE

TABLE 6: MLD-10 CYCLE WITH 10 SECOND RAMPS

STAGE	MPH	TIME	DC	DC
		seconds	RPM	TPS (%WOT)
IDLE	0	80	800	1.500
RAMP UP	-	10	1600	5.794
1	30	620	1600	5.794
RAMP DN	-	30	800	1.500
IDLE	0	80	800	1.500
RAMP UP	-	10	3100	18.765
2	70	620	3100	18.765
RAMP DN	-	30	800	1.500
IDLE	0	80	800	1.500
RAMP UP	-	10	1600	5.794
3	30	620	1600	5.794
RAMP DN	-	30	800	1.500
IDLE	0	80	800	1.500
RAMP UP	-	10	1800	7.636
4	40	620	1800	7.636
RAMP DN	-	30	800	1.500
IDLE	0	80	800	1.500
RAMP UP	-	10	2700	13.915
5	60	620	2700	13.915
RAMP DN	-	30	800	1.500
IDLE	0	80	800	1.500
THIS	IS	1	HOUR	CYCLE
CHANGE	OIL	100	200	HOURS

III. TEST PROCEDURES

The program was developed to run 80 total tests – 40 on the GM engines, and 40 on the DC engines. The runs were to alternate test cycles, and have the fuel packages assigned at random. The manufacturers supplied the first engines. They also supplied dyno-wiring harnesses, and modified electronic control modules (**ECM**). Several parameters related to OBD-II such as knock sensors and ignition interlocks were disabled. PerkinElmer Automotive Research (**PEAR**) then purchased another set of cylinder heads for each engine, and all spare engines and parts for dyno installation and operations. The heads were rotated. The first head would run a test while the second head was being rebuilt for the next test. It was planned to run about 10 tests on each block, and 5 tests on each cylinder head combination. Each test would be 300 hours in length. Break-in for each new engine would follow the IVD (**ASTM D6201**) break-in procedure. Table 3 shows the first half of the tests and cycles. The GM series of testing was cancelled at the completion of these tests. The DC engines continued to run a modified MAMA cycle with soaks. Table 7 shows the test numbers, cycles and additives for those tests.

Ramps were developed with the intent of simulating the engine operation working through the torque converter of an automatic transmission. This meant very fast ramps of RPM and

TPS to steady state conditions, then holding those values until the steady state conditions were achieved. Early work was with 3 second ramps, but these broke drivelines, and destroyed one DC engine due to 3 oil pump failures. A programmer was brought in to develop “feed forward” steps to allow the two conditions to meet the 6 second goals. All stands were converted to a digital dynamometer control system, as the older version clamped too quickly and added to driveline damage.

As part of the transmission simulation, the ramp for each stage was held at the ramp value for 3 seconds for each 10 MPH increment. As an example, in ramping from idle to 60 MPH, there would be a 6 second ramp to 3000 RPM and 60 % TPS [for the DC engine]. That condition would be held for 18 seconds, then ramp down to the 60 MPH control conditions.

Drivelines were converted to damped systems to survive the ramps and the resultant torsionals vibrations. The constant velocity drive shafts were replaced with universal joints for the same reason. Later in testing, it was determined that these ramps were using significantly more fuel than the vehicles, and the cycles were converted back to more traditional linear ramps of varied length to attempt to match vehicle fuel consumption.

TABLE 3: DYNAMOMETER CCD TEST ORDER

TEST NUMBER	CYCLE	FUEL	TEST NUMBER	CYCLE	FUEL
GM12-01-0001	MAMA	**B**	GM13-01-0001	SIMPLE	**A**
GM12-02-0002	SIMPLE	**D**	GM13-02-0002	MAMA	**B**
GM12-03-0003	MAMA	**A**	GM13-03-0003	SIMPLE	**E**
GM12-04-0004	SIMPLE	**B**	GM13-04-0004	MAMA	**E**
GM12-05-0005	MAMA	**E**	GM13-05-0005	SIMPLE	**D**
GM12-06-0006	SIMPLE	**A**	GM13-06-0006	MAMA	**D**
GM12-07-0007	MAMA	**D**	GM13-07-0007	SIMPLE	**C**
GM12-08-0008	SIMPLE	**C**	GM13-08-0008	MAMA	**A**
GM12-09-0009	MAMA	**C**	GM13-09-0009	SIMPLE	**B**
GM12-10-0010	SIMPLE	**E**	GM13-10-0010	MAMA	**C**
TEST NUMBER	**CYCLE**	**FUEL**	**TEST NUMBER**	**CYCLE**	**FUEL**
DC2-01-0001	MAMA	**D**	DC3-01-0001	SIMPLE	**E**
DC2-02-0002	SIMPLE	**A**	DC3-02-0002	MAMA	**C**
DC2-03-0003	MAMA	**C**	DC3-03-0003	SIMPLE	**D**
DC2-04-0004	SIMPLE	**D**	DC3-04-0004	MAMA	**A**
DC2-05-0005	MAMA	**B**	DC3-05-0005	SIMPLE	**C**
DC2-06-0006	SIMPLE	**C**	DC3-06-0006	MAMA	**E**
DC2-07-0007	MAMA	**A**	DC3-07-0007	SIMPLE	**B**
DC2-08-0008	SIMPLE	**E**	DC3-08-0008	MAMA	**B**
DC2-09-0009	MAMA	**E**	DC3-09-0009	SIMPLE	**A**
DC2-10-0010	SIMPLE	**B**	DC3-10-0010	MAMA	**D**

TABLE 4: NEON RUNS FOR MAMA CYCLE WITH SOAK

TEST NUMBER	CYCLE	FUEL	TEST NUMBER	CYCLE	FUEL
DC2-11-0011	MMASOAK	**D**	DC3-11-0011A	MMASOAK	**A**
DC2-12-0012A	MMASOAK	**C**	DC3-12-0012	MMASOAK	**E**
DC2-13-0013	MMASOAK	**E**	DC3-13-0013	MMASOAK	**C**
DC2-14-0014	MMASOAK	**A**	DC3-14-0014	MMASOAK	**D**
DC2-15-0015	MMASOAK	**C**	DC3-15-0015	MMASOAK	**D**
DC2-16-0016	MMASOAK	**E**	DC3-16-0016	MMASOAK	**A**

At the completion of the MAMA cycle with soak tests, the decision was made to create a cycle that would be even easier to transfer to other labs. Ramp times were reduced from 6 seconds to either 10 or 15 seconds, depending on the cycle. Cycle names indicated the ramp time. Appendix A shows the different cycles and the trapezoid ramps. When the tests were converted to linear ramps, the ramp was from idle to the operating conditions of the next steady state, not to a plateau, then a ramp down to the stage set points.

Also at this time, the decision was also made to run all tests on one stand with one block and two sets of heads. One additional cycle was created with fewer steady state conditions compared to the SIMPLE cycle. It was called the MILDER cycle. Table 5 shows the test numbers and additive for those runs.

TABLE 5: NEON RUNS FOR MILDER, MLD-10 AND SIM-15 CYCLES

TEST NUMBER	CYCLE	FUEL	TEST NUMBER	CYCLE	FUEL
DC2-17-0017	MILDER	**D**	DC3-25-0025	SIM-15	**E**
DC2-18-0018	MILDER	**E**	DC3-26-0026	MLD-10	**E**
DC2-19-0019	MILDER	**E**	DC3-27-0027	MLD-10	**E**
DC2-20-0020	MILDER	**D**	DC3-28-0028	MLD-10	**D**
DC2-21-0021	MLD-10	**E**	DC3-29-0029	MLD-10	**D**
DC2-22-0022	MLD-10	**D**	DC3-30-0030	MLD-10	**A**
DC2-23-0023	MLD-10	**D**	DC3-31-0031	MLD-10	**B**
DC2-24-0024	SIM-15	**D**	DC3-32-0032	MLD-10	**C**

A. TEST FUEL, ADDITIVES, ANALYSIS, AND ENGINE OIL

1. Base Fuel

Unadditized Phillips RF-A unleaded gasoline was chosen as the base fuel. This was purchased as one batch to run the entire vehicle and dynamometer program. This fuel was stored at the manufacturer's facility, and delivered to the lab as needed. It was stored in a 12, 000 gallon tank.

2. Fuel Additives

Fuel additives were received from Southwest Research (SwRI). Prior to the start of each test, raw additive was delivered to the chemistry lab to be measured. Fuel/additive combinations were done by 250-gallon batches in totes. As each test completed, the totes were flushed with base fuel prior to mixing the new batch. Two totes were used only for the base fuel to avoid contamination.

3. Fuel Analysis

Early in the program we had not run gums on the fuel mixtures. When we did start taking gum data, each fuel batch was measured for gums (ASTM D 381). We then used the Ford TGA method specified by Chuck Richardson. This method was developed to determine the likelihood of a fuel to form CCD. Gums produced from D 381 are rinsed in solvent to gather enough residues. The gums were baked to 150ºC at 5 ºC /min. A soak was done for 5 minutes, and the mass weighed again to give the initial sample mass A second ramp was done from 150ºC to 500ºC. The residue is then weighed to give a percent weight loss. This data was supposed to be stored in a file. We did not do that step. Later in the program, one batch of each additive used in each cycle was measured, and that information is available.

4. **Engine Oil**

Motorcraft SAE 5W30 Super Premium Motor oil was used for all tests. This was supplied from the new batch of ASTM D6201 oil. Oil consumption was monitored during the test, and the oil was changed every 100 hours. The oil fills and drains were weighed to determine consumption, and that value converted to ounces.

B. TEST ENGINES

1. **GM Engines**

Two 1999 model 6.0 litre modular V-8 engines were pulled from the assembly line for the dynamometer tests. A meeting was held with the GM test engineer in Detroit to determine the configuration and modifications needed to install the engines on stands. GM also supplied special wiring harnesses and modified ECM. These engines were of the same year model and met the same emissions standards as the engines in the vehicles purchased by SwRI.

2. **DC Engines**

Two 2.0 litre I-4 engines were also pulled from the assembly line for this research. However, DaimlerChysler had already converted their assembly line to the 2000-year model engines, and these did not include exhaust gas recirculation (**EGR**), and had other changes compared to the 1999 models used in the vehicle testing. DC also supplied wiring harnesses and modified ECMs. These had to be reprogrammed, as their dynamometers used air starters, and on PEAR electric starter stands, the engines would start rich and foul the plugs. The DC test engineer changed the turn-on point for the fuel injectors.

3. **Replacement Parts**

For all testing, additional cylinder heads and engines were purchased, along with intake and exhaust valves, rebuild kits, and spare parts. The heads were alternated for each test start on each engine. The engine blocks were replaced every 10 tests, and the heads every 5 tests, unless mechanical failure or excess wear were indicated.

C. TEST CYCLES

1. **MAMA Cycle**

The first cycle was based on data collected from the vehicles, and the published cycle was called Modified Alternate Mileage Accumulation. The major changes for the dynamometer were removal of "key-off" events (which were replaced by idle periods), and the use of trapezoidal ramps from idle to the steady state conditions. There were a series of ramps and steady-state segments over a two-hour period. Oil and coolant temperatures were based on the vehicle data, and the engine was controlled to RPM and TPS location.

2. **SIMPLE Cycle**
   This cycle was based on the same steady-state conditions from the vehicles, but only had 8 steady-state segments over a one-hour period. The ramps from idle to steady state were the same trapezoid ramps.

3. **MAMA Cycle With Soaks**
   It was determined that removing the "key-off" events might have had an effect on the deposits, especially on the base fuel, so the MAMA cycle was modified to run 16 hours, then soaked overnight. 12 tests were run in this configuration to give 3 results each on each of the different additives. Additive B was removed as it was considered similar another additive.

4. **MILDER Cycle**
   This cycle reduced the high speed steady state conditions, and the number of cycles down to five to simplify programming. Only a few tests were run to these conditions, as deposits increased.

5. **MILDER-10 Cycle**
   This cycle was a modification of the SIMPLE cycle in an effort to duplicate the fuel consumption of the vehicles. The MAMA cycle used about 60% more fuel than the vehicles, and the SIMPLE cycles used about 20% more. This cycle eliminated the trapezoid ramps, and had 5 steady-state conditions. Those were reached by a 10 second linear ramp from the idle condition (hence the name) to the steady state conditions.

6. **SIM-15 Cycle**
   This was the SIMPLE cycle with the trapezoid ramps changed to 15-second ramps from idle to steady state. It ran lower fuel consumption that the vehicles, and only two tests were run to these conditions.

D. TEST PROCEDURES

1. **Break-in**
   a. For each new engine, break-in was performed per the IVD procedure (**ASTM D6201**).
   b. A leak-down and compression test was performed at the start of each test. This was no longer done when one block was selected to complete all remaining testing.
2. **Engine Build**
   a. Each cylinder head was disassembled completely. New valves were used on each new build. Raw valve weights were taken, and guide to stem measurements confirmed to be within factory specification. When guides exceeded the limits, the head was replaced.
   b. Either from break-in or the previous test, the piston tops and block surface were scraped clean. New gaskets and spark plugs were used for the head installation. All vacuum lines, electrical connections, and coolant plumbing were inspected and replaced as needed. Fuel injectors were cleaned, and replaced as needed.

c. After head installation, the engine was run for 30 minutes, and then a leak-down and compression test performed. This step was removed when the decision was made to use the same block for multiple tests.

d. A 50/50% anti-freeze and water mixture was used for coolant. The GM engines used extended life DexCool (orange in color), and the DC engines used factory specified anti-freeze (green in color).

e. Fuel pressure was very sensitive on the DC engines, and they had to be converted to a return system. This was done with a Paxton fuel pressure regulator. The vehicles use a return regulator inside the gas tank.

3. Test Operation

a. At the start of each test, the engineer would supply a manual data log package for the desired test cycle; the operator would choose the program on the computer to run that cycle.

b. The engine would be started, run for 30 minutes, then shut down to perform leak-down and compression tests.

c. The engine would be restarted, placed on test, and run until the 100-hour oil change. The engine would automatically shut down for this event. The engine might be left down for any necessary maintenance at this time.

d. This procedure would repeat at 200 and 300 hour marks. The oil and oil filter would be weighed each time to calculate oil consumption for the engine. An oil sample was taken to the chemistry lab every 100 hours to perform fuel dilution percentage measurements (**ASTM D3525M**).

e. For all test cycles, the critical control parameters were RPM and TPS. This controlled both steady state and ramp conditions. Oil and coolant temperature were controlled to values similar to the vehicles. One engine of each type had the exhaust system prepared to take exhaust temperatures. Exhaust back pressure (**EBP**) was controlled with a valve set to give 30.6 inches of water, and to run at ambient pressure at idle. Intake air pressure was controlled to 0.20 inches of water.

f. Early in the program during the trapezoid ramps, an Agilent data recorder was used to record the ramps of RPM and TPS.

g. Temperature and humidity controlled intake air were supplied to each engine from a central supply.

h. Fuel consumption was measured by a dipstick recording at the totes.

4. End of Test Procedures

a. At EOT, the cylinder head was removed and taken to a temperature and humidity controlled environment. Early in the program, photographs were taken of the piston tops, combustion chambers, and intake vales for each engine type in each cycle for each additive. Every effort was made to remove the head within 24 hours of EOT to minimize deposit flaking. The engine block would remain at the stand.

b. With the head removed, the Rater would visually rate piston tops, cylinder bore surfaces, valve faces and intake runners. Intake valves would then be removed, and the IVD deposits, and valve tulips would be rated as well.

c. Next CCD thickness measurements would be taken using the template supplied by SwRI. Those numbers were stored on a computer for the test report. A Fischer Permascope Model D211 was used for thickness measurements.

d. Next, the piston tops and cylinder bore surfaces were carefully scraped, and all deposits collected, and taken to metrology for weights.

e. Finally the valves were cleaned and weighed per the IVD procedure (**ASTM D6201**).

f. All collected data was then sent to the engineer to complete the test report.

g. The fuel totes would then be drained and flushed in preparation for the next test start if the additive was changing for the next test.

IV. RESULTS

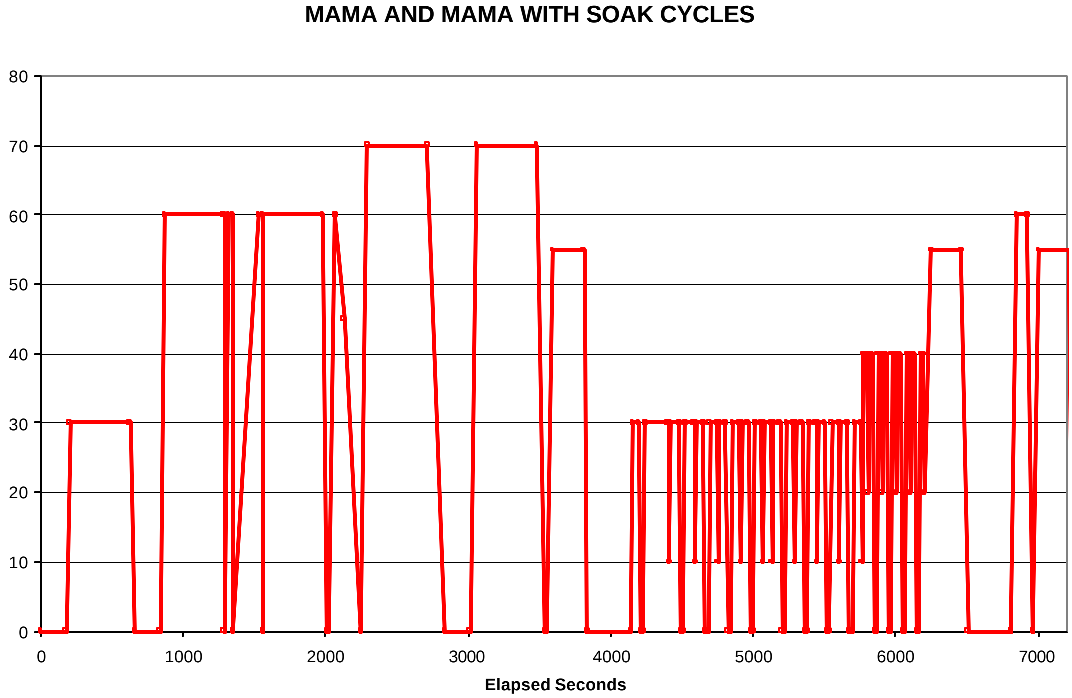
The averages results for all dynamometer tests separated by test cycle and engine type are shown in Appendix B. Individual sheets for the GM and DC tests are shown in Appendix C and D.

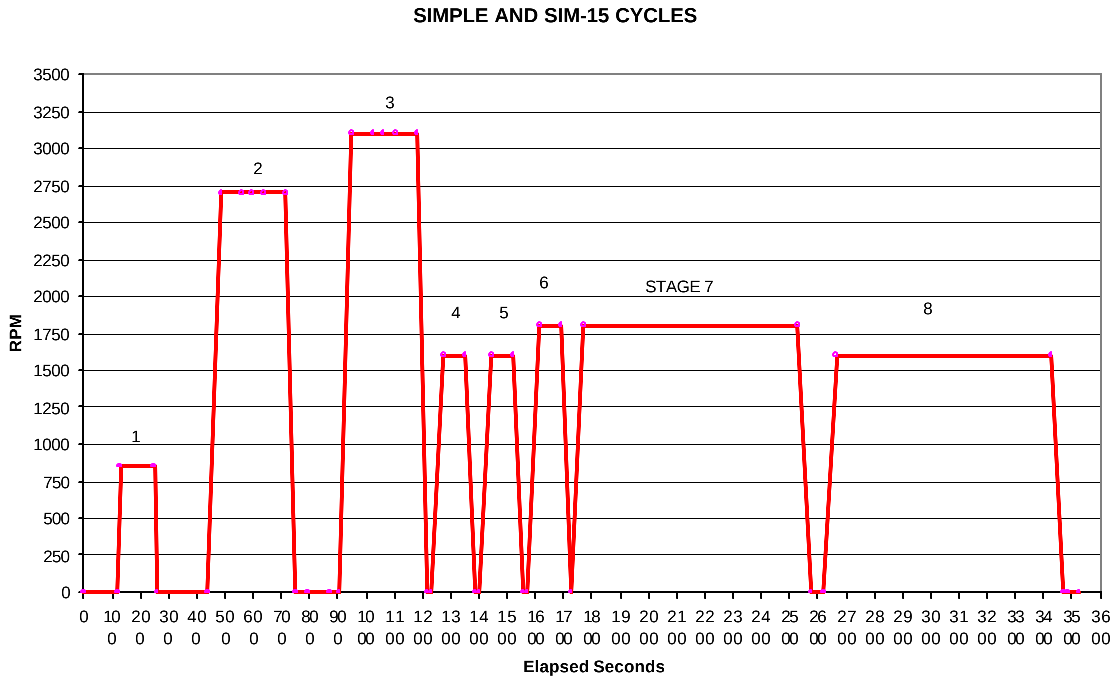
V. SUMMARY

The original goals of running the MAMA cycle and another easier to program cycle were met. However, a significant concern was that none of the cycles or engines was able to duplicate the low CCD numbers generated by the vehicle tests on the base fuel. Cycle and ramp modifications were made to achieve that goal. In this effort, several tests were run only on the high CCD additive and the base fuel. The MLD-10 cycle was selected to complete the program, and one run was made on additives A, B, and C. The objective of duplicating vehicle results was not achieved for the base fuel.

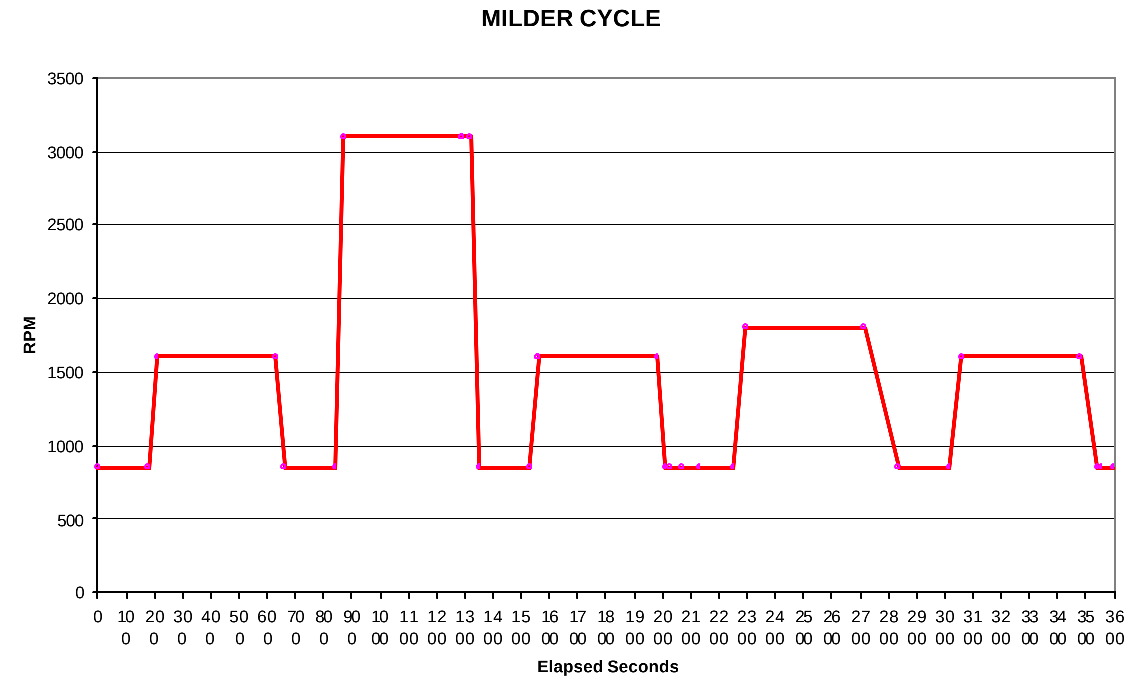
At the start of the program for tests GM12-01 and 02 and GM13-01 and 2, and on tests DC2-30, 31, and 32 CCD thickness was affected by operator technique. The test lab recommended that data not be used in analysis. At the end of the program, new operators at PEAR were performing thickness measurements intake valve deposit weights, and much greater variability was seen in the results. This would also be test DC2-30, 31, and 32.

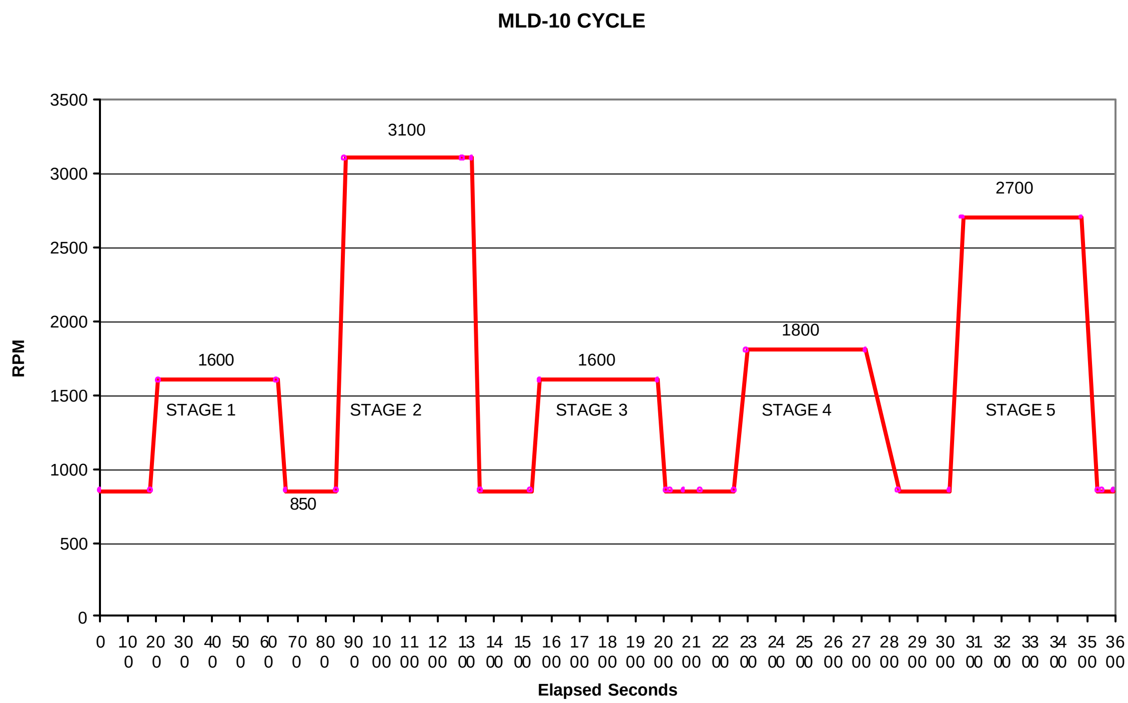
APPENDIX A

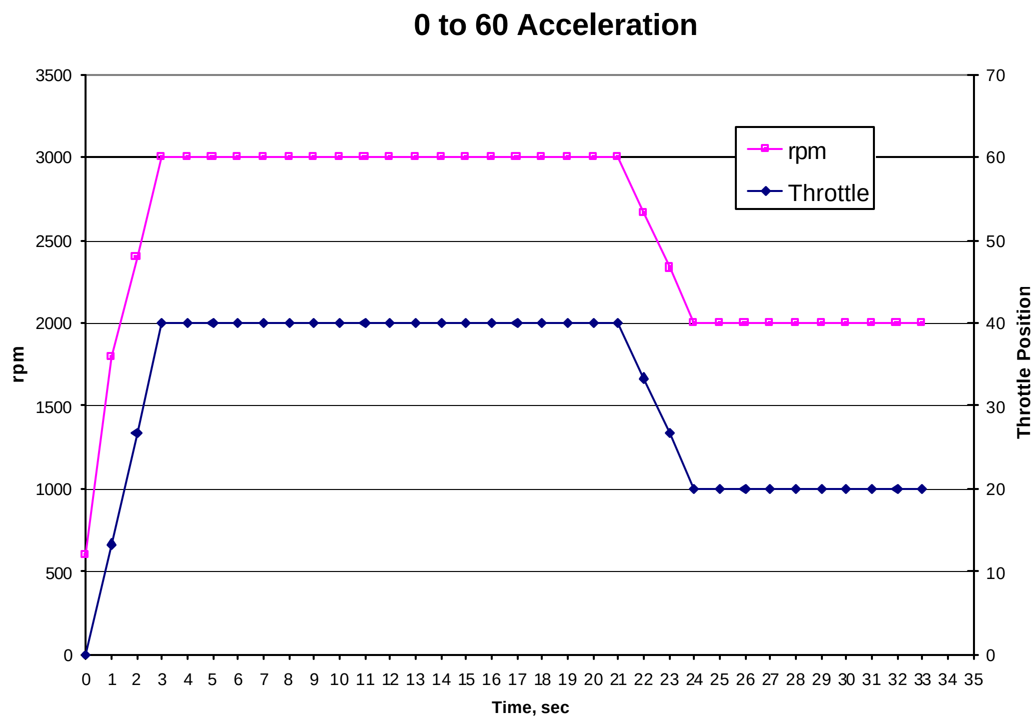

MAMA AND MAMA WITH SOAK CYCLES
80
70
60
50
40
30
20
10
0
0
1000
2000
3000
4000
5000
6000
7000
Elapsed Seconds



SIMPLE AND SIM-15 CYCLES
RPM
3500
3250
3000
2750
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
1
2
3
4
5
6
STAGE 7
8
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500 2600 2700 2800 2900 3000 3100 3200 3300 3400 3500 3600
Elapsed Seconds


MILDER CYCLE
RPM
Elapsed Seconds


MLD-10 CYCLE
RPM
3100
2700
1800
1600
1600
850
STAGE 1
STAGE 2
STAGE 3
STAGE 4
STAGE 5
Elapsed Seconds



0 to 60 Acceleration
rpm
Throttle
Throttle Position
Time, sec

APPENDIX B

								THICKNESS						IVD	CCD			CCD				
			GAL/	FUEL				PISTON		HEAD		AVERAGE		WEIGHT	WEIGHTS			RATINGS				
TEST NUMBER	CYCLE	FUEL	HOUR	DIL, %	HEAD	BLOCK	EOT	MILS	MM	MILS	MM	MILS	MM	MG	PISTON	HEAD	TOTAL	RUNNER	TULIP	PORT	PISTON	CHAMBER
GM12-03-0003	MAMA	A			01,02	1	05.19.2000	9.494	0.241	6.721	0.171	8.108	0.206	12.2	9.005	8.980	17.985	9.634	9.713	8.676	7.005	7.442
GM13-08-0008	MAMA	A			03,04	1	09.13.2000	5.121	0.130	6.128	0.156	5.624	0.143	6.6	9.139	10.106	19.245	9.328	9.550	8.652	7.110	7.195
GM12-01-0001	MAMA	B			01,02	1	03.08.2000	8.236	0.209	6.561	0.167	7.399	0.188	37.1	10.320	8.135	18.456	9.702	9.313	9.259	7.237	7.578
GM13-02-0002A	MAMA	B			03,04	1	05.19.2000	7.605	0.193	6.105	0.155	6.855	0.174	30.1	10.011	7.166	17.177	9.707	9.425	9.255	7.084	7.433
GM12-09-0009	MAMA	C			01,02	1	09.09.2000	3.971	0.101	6.643	0.169	5.307	0.135	355.4	8.024	8.347	16.371	8.976	7.850	7.461	7.652	7.937
GM13-10-0010	MAMA	C			03,04	1	10.20.00	4.150	0.105	5.051	0.128	4.601	0.117	43.3	8.183	9.430	17.613	9.166	8.863	8.097	7.979	8.217
GM12-07-0007	MAMA	D			01,02	1	07.31.2000	5.298	0.135	6.491	0.165	5.894	0.150	4.3	12.042	9.408	21.450	9.715	9.588	9.546	6.960	7.380
GM13-06-0006	MAMA	D			03,04	1	08.01.2000	8.231	0.209	8.629	0.219	8.430	0.214	17.7	15.408	14.552	29.960	9.636	9.263	9.506	7.331	7.252
GM12-05-0005	MAMA	E			01,02	1	06.26.2000	9.403	0.239	9.050	0.230	9.226	0.234	845.5	6.732	9.670	16.403	8.904	7.475	7.122	7.543	7.528
GM13-04-0004	MAMA	E			03,04	1	06.26.2000	10.819	0.275	7.913	0.201	9.366	0.238	867.2	6.732	8.211	14.943	9.272	7.275	7.274	7.402	7.651
GM12-02-0006	SIMPLE	A			03,04	1	07.13.2000	11.831	0.301	5.850	0.149	8.841	0.225	7.0	7.400	8.501	15.901	9.046	9.5	9.136	7.718	8.172
GM13-01-0001	SIMPLE	A			01,02	1	03.03.2000	4.148	0.105	4.694	0.119	4.421	0.112	10.9	9.178	10.017	19.195	9.404	9.825	9.025	7.844	7.808
GM12-04-0004	SIMPLE	B			03,04	1	06.07.2000	10.325	0.262	8.568	0.218	9.446	0.240	22.2	8.962	7.835	16.797	9.666	9.575	9.399	7.467	7.655
GM13-09-0009	SIMPLE	B			01,02	1	10.04.00	5.264	0.134	5.065	0.129	5.164	0.131	2.9	9.288	7.794	17.082	9.614	9.750	9.474	7.329	7.747
GM12-08-0008	SIMPLE	C			03, 04	1	08.20.2000	4.119	0.105	5.358	0.136	4.738	0.120	255.9	8.562	8.208	16.770	8.578	7.738	7.362	7.841	7.712
GM13-07-0007	SIMPLE	C			01,02	1	08.21.2000	4.379	0.111	5.678	0.144	5.028	0.128	212.2	7.817	8.441	16.258	8.375	8.413	7.558	7.436	7.456
GM12-02-0002	SIMPLE	D			03,04	1	03.24.2000	10.075	0.256	5.665	0.144	7.870	0.200	2.9	12.377	10.330	22.707	9.682	9.900	9.311	7.152	7.485
GM13-05-0005	SIMPLE	D			01,02	1	07.16.2000	16.354	0.415	11.808	0.300	14.081	0.358	66.7	15.200	14.364	29.565	9.483	8.2	9.357	6.995	7.055
GM12-10-0010	SIMPLE	E			03,04	1	09.26.2000	3.990	0.101	6.490	0.165	5.240	0.133	661.3	8.719	10.046	18.766	8.635	7.688	7.109	8.047	8.009
GM13-03-0003	SIMPLE	E			01,02	1	06.05.2000	11.709	0.297	6.626	0.168	9.168	0.233	476.2	9.619	7.462	17.081	8.373	7.813	7.404	7.629	7.902

								THICKNESS						IVD	CCD			CCD				
			GAL/	FUEL				PISTON		HEAD		AVERAGE		WEIGHT	WEIGHTS			RATINGS				
TEST NUMBER	CYCLE	FUEL	HOUR	DIL, %	HEAD	BLOCK	EOT	MILS	MM	MILS	MM	MILS	MM	MG	PISTON	HEAD	TOTAL	RUNNER	TULIP	PORT	PISTON	CHAMBER
DC2-07-0007	MAMA	A	2.17		2	2	11.08.00	5.393	0.137	2.314	0.059	3.853	0.098	9.6	4.165	3.111	7.275	9.713	9.625	9.423	7.466	7.602
DC3-04-0004	MAMA	A	2.17		2	1	10.21.00	6.310	0.160	5.972	0.152	6.141	0.156	4.4	5.928	3.713	9.641	9.646	9.588	9.448	7.433	7.631
DC2-05-0005	MAMA	B	2.17		2	2	10.09.00	4.939	0.125	4.829	0.123	4.884	0.124	4.4	3.333	2.988	6.321	9.67	9.463	9.771	7.401	7.507
DC3-08-0008	MAMA	B	2.17		2	1	02.27.2001	4.683	0.119	4.406	0.112	4.544	0.115	11.4	3.658	2.503	6.161	9.616	9.088	9.659	7.676	7.722
DC2-03-0003	MAMA	C	2.17		1	2	07.18.2000	4.040	0.103	4.973	0.126	4.506	0.114	543.3	3.709	3.168	6.877	9.098	6.900	8.765	8.112	7.352
DC3-02-0002	MAMA	C	2.17		2	1	9.14.2000	5.268	0.134	5.505	0.140	5.387	0.137	497.3	4.091	3.351	7.442	9.258	7.000	8.962	7.855	7.139
DC2-01-0001A	MAMA	D	2.17		3	2	02.21.2001	6.318	0.160	7.562	0.192	6.940	0.176	1.4	4.685	3.764	8.450	9.774	9.263	9.650	7.450	7.374
DC3-10-0010	MAMA	D	2.17		2	1	03.27.2001	6.368	0.162	6.968	0.177	6.668	0.169	3.4	5.108	3.848	8.956	9.755	9.600	9.854	7.317	7.544
DC2-09-0009	MAMA	E	2.17		2	2	01.15.01	3.755	0.095	5.296	0.135	4.526	0.115	522.2	2.377	3.425	5.802	8.721	5.863	7.901	8.403	7.807
DC3-06-0006A	MAMA	E	2.17		2	1	01.24.01	3.497	0.089	5.999	0.152	4.748	0.121	531.3	2.899	2.937	5.837	8.080	6.638	7.908	8.100	7.530
DC2-02-0002A	SIMPLE	A	1.67		2	2	03.08.2001	8.194	0.208	7.156	0.182	7.675	0.195	1.3	5.460	4.832	10.291	9.466	9.838	9.542	7.079	7.212
DC3-09-0009	SIMPLE	A	1.67		1	1	03.14.2001	6.280	0.160	6.630	0.168	6.455	0.164	1.0	4.970	4.042	9.012	9.510	9.675	9.535	7.783	7.465
DC2-10-0010	SIMPLE	B	1.67		3	2	02.06.01	6.623	0.168	6.562	0.167	6.593	0.167	1.4	4.401	2.904	7.306	9.724	9.763	9.748	7.047	7.154
DC3-07-0007	SIMPLE	B	1.67		1	1	02.12.01	6.848	0.174	6.919	0.176	6.883	0.175	6.4	5.046	3.140	8.186	9.770	9.688	9.715	7.325	7.784
DC2-06-0006	SIMPLE	C	1.67		3	2	10.24.00	6.047	0.154	4.414	0.112	5.230	0.133	28.8	4.057	3.514	7.571	9.352	8.750	8.866	7.945	7.322
DC3-05-0005	SIMPLE	C	1.67		1	1	11.07.01	5.341	0.136	6.198	0.157	5.770	0.147	4.8	3.896	3.307	7.204	9.262	9.288	8.998	7.631	7.460
DC2-04-0004A	SIMPLE	D	1.67		3	2	09.16.2000	6.087	0.155	7.510	0.191	6.798	0.173	4.7	4.402	4.141	8.543	9.497	8.325	9.654	7.388	6.923
DC3-03-0003	SIMPLE	D	1.67		1	1	10.02.00	4.939	0.125	4.829	0.123	4.884	0.173	4.4	3.333	2.988	9.071	9.67	9.463	9.771	7.401	7.507
DC2-08-0008	SIMPLE	E	1.67		3	2	12.27.00	4.997	0.127	7.551	0.192	6.274	0.159	497.0	3.706	3.684	7.390	9.114	6.675	7.605	7.771	7.828
DC3-01-0001	SIMPLE	E	1.67		1	1	08.18.2000	3.741	0.095	4.454	0.113	4.098	0.104	520.5	2.684	2.866	5.550	8.736	6.975	7.630	7.422	7.548
DC2-14-0014	MMASOAK	A	2.17		6	4	08.29.2001	6.155	0.156	5.723	0.145	5.939	0.151	9.5	5.089	3.030	8.118	9.726	9.638	9.677	8.020	7.961
DC3-11-0011A	MMASOAK	A	2.17		3	3	08.12.2001	3.858	0.098	1.355	0.034	2.607	0.066	2.1	2.698	1.526	4.225	9.603	9.538	9.587	7.500	7.866
DC3-16-0016	MMASOAK	A	2.17		3	3	11.12.2001	5.466	0.139	5.743	0.146	5.604	0.142	1.4	4.234	4.048	8.282	9.656	9.825	9.614	7.720	7.725
DC2-12-0012A	MMASOAK	C	2.17		6	4	07/28.2001	6.175	0.157	4.303	0.109	5.239	0.133	168.5	5.303	3.385	8.689	9.743	8.213	9.111	7.598	7.512
DC2-15-0015	MMASOAK	C	2.17		5	4	09.18.2001	5.202	0.132	5.808	0.148	5.505	0.140	131.6	4.675	3.416	8.091	9.609	8.263	9.360	8.318	7.518
DC3-13-0013	MMASOAK	C	2.17		3	3	09.11.2001	4.478	0.114	5.378	0.137	4.928	0.125	25.3	3.653	2.830	6.483	9.469	9.138	9.118	7.278	7.105
DC3-14-0014	MMASOAK	D	2.17		4	3	10.03.2001	4.464	0.113	4.341	0.110	4.403	0.112	7.0	3.088	2.671	5.759	9.688	9.888	9.786	7.944	7.925
DC2-11-0011	MMASOAK	D	2.17		5	4	06.15.2001	5.645	0.143	5.266	0.134	5.456	0.139	2.3	4.532	4.004	8.537	9.769	9.450	9.751	7.964	7.705
DC3-15-0015	MMASOAK	D	2.17		3	3	10.27.2001	5.240	0.133	5.385	0.137	5.313	0.135	6.3	3.931	3.494	7.425	9.817	9.863	9.806	8.019	7.916
DC2-13-0013	MMASOAK	E	2.17		5	4	08.12.2001	4.489	0.114	5.747	0.146	5.118	0.130	404.1	3.631	3.108	6.739	9.472	6.850	8.106	7.758	7.898
DC3-12-0012	MMASOAK	E	2.17		4	3	08.28.2001	3.095	0.079	4.873	0.124	3.984	0.101	342.4	2.675	2.605	5.279	9.167	7.380	8.517	8.315	8.229
DC2-16-0016	MMASOAK	E	2.17		6	4	10.04.2001	6.315	0.160	6.076	0.154	6.195	0.157	528.2	5.407	3.167	8.574	9.404	6.388	8.672	8.198	8.034
DC2-17-0017	MILDER	D	0.93		5	4	01.18.2002	7.039	0.179	8.072	0.205	7.556	0.192	3.9	5.538	5.036	10.574	9.595	9.250	9.580	7.133	7.152
DC2-18-0018	MILDER	E	0.93		6	4	02.05.2002	4.941	0.126	8.624	0.219	6.782	0.172	701.6	4.363	4.379	8.742	8.904	6.550	7.725	8.082	7.641
DC2-19-0019	MILDER	E	0.93		5	4	02.26.2002	5.142	0.131	7.871	0.200	6.506	0.165	749.3	3.813	4.708	8.521	8.553	6.913	6.981	7.645	7.098
DC2-20-0020	MILDER	D	0.93		6	4	03.18.2002	6.899	0.175	8.829	0.224	7.864	0.200	1.8	5.478	5.166	10.643	9.550	9.588	9.474	6.999	6.701
DC2-21-0021A	MLD-10	E	1.38		7	4	07.10.2002	3.539	0.090	5.581	0.142	4.560	0.116	621.4	3.105	3.141	6.247	9.077	6.700	7.793	7.782	7.966
DC2-22-0022	MLD-10	D	1.38		8	4	07.25.2002	5.170	0.131	6.193	0.157	5.681	0.144	3.8	4.461	4.184	8.644	9.846	9.200	9.698	7.567	7.688
DC2-23-0023	MLD-10	D	1.38	1.6	7	4	08.12.2002	5.525	0.140	6.809	0.173	6.167	0.157	2.4	5.032	4.183	9.215	9.807	9.513	9.743	8.232	8.172
DC2-26-0026	MLD-10	E	1.38	1.6	8	4	04.17.2003	3.760	0.096	6.555	0.166	5.157	0.131	777.1	4.150	3.414	7.564	9.182	6.725	8.190	7.565	7.262
DC2-27-0027	MLD-10	E	1.38	1.6	7	4	05.01.2003	3.895	0.099	7.240	0.184	5.568	0.141	714.3	3.765	3.871	7.636	9.484	6.388	7.812	7.428	7.424
DC2-28-0028	MLD-10	D	1.38	1.6	8	4	05.19.2003	15.138	0.384	6.962	0.177	11.050	0.281	8.0	4.593	3.606	8.199	9.628	9.525	9.648	7.120	7.109
DC2-29-0029A	MLD-10	D	1.38	1.6	7	4	06.19.2003	5.059	0.129	7.324	0.186	6.192	0.157	11.2	4.692	4.343	9.035	9.690	9.588	9.685	7.183	7.088
DC2-30-0030	MLD-10	A	1.38	1.6	8	4	07.09.2003	6.378	0.162	6.630	0.168	6.504	0.165	202.1	4.186	3.451	7.637	9.416	9.513	9.086	7.158	7.297
DC2-31-0031	MLD-10	B	1.38	1.6	7	4	07.23.03	4.531	0.115	6.136	0.156	5.334	0.135	353.8	4.347	3.023	7.370	9.709	9.703	9.632	7.590	7.479
DC2-32-0032	MLD-10	C	1.38	1.6	8	4	08.08.03	6.503	0.165	7.937	0.203	7.238	0.184	251.9	3.978	3.979	7.957	9.654	7.838	8.757	7.699	7.269
DC2-24-0024	SIM-15	D	1.27	1.3	8	4	09.04.2002	7.001	0.178	7.939	0.202	7.470	0.190	1.7	5.194	4.836	10.030	9.553	9.550	9.500	7.124	7.238
DC2-25-0025	SIM-15	E	1.27	1.6	7	4	09.28.2002	4.069	0.103	6.766	0.172	5.417	0.138	725.1	3.307	4.155	7.462	9.115	6.825	7.899	7.563	7.772

APPENDIX C

GM CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMA	GM12-01-0001	01,02	B	RF-A	ORLANDO	03.07.2000	
	AVERAGE	UNITS	1	2	3	4	5	6	7	8
PISTON THICKNESS	8.236	mils	5.850	8.590	7.330	7.990	8.480	8.850	10.250	8.550
	0.209	mm	0.149	0.218	0.186	0.203	0.215	0.225	0.260	0.217
HEAD THICKNESS	6.561	mils	6.700	6.600	6.320	6.390	5.580	6.590	6.850	7.460
	0.167	mm	0.170	0.168	0.161	0.162	0.142	0.167	0.174	0.189
THICKNESS AVERAGE	7.399	mils								
	0.188	mm								
IVD WEIGHTS	NA	mg	NA	NA	NA	NA	NA	NA	NA	NA
	TOTALS									
PISTON WEIGHTS	10.320	gm	1.3684	1.3815	1.3216	1.1725	1.2659	1.3458	1.7579	0.7068
HEAD WEIGHTS	8.135	gm	0.9206	0.9699	0.9182	1.0555	0.9260	1.0553	1.1673	1.1226
TOTAL CCD WEIGHTS	18.456	gm								
RATINGS										
INTAKE RUNNER	9.702	merit	9.712	9.701	9.672	9.684	9.684	9.712	9.704	9.746
VALVE TULIP	9.313	merit	9.400	9.500	9.100	9.300	9.200	9.000	9.400	9.600
INTAKE PORT	9.259	merit	9.334	9.350	9.299	9.274	8.977	9.140	9.352	9.348
PISTON TOP	7.237	merit	7.385	7.152	7.426	7.144	7.345	7.068	7.186	7.188
CHAMBER	7.578	merit	7.488	7.562	7.612	7.612	7.604	7.503	7.666	7.574

GM CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			SIMPLE	GM1-02-0002	03,04	D	RF-A	ORLANDO	03.25.00	
	AVERAGE	UNITS	1	2	3	4	5	6	7	8
PISTON THICKNESS	10.075	mils	8.430	11.140	9.950	10.660	10.290	10.600	9.430	10.100
	0.256	mm	0.214	0.283	0.253	0.271	0.261	0.269	0.240	0.257
HEAD THICKNESS	5.665	mils	5.550	5.340	5.770	5.750	5.700	5.820	5.620	5.770
	0.144	mm	0.141	0.136	0.147	0.146	0.145	0.148	0.143	0.147
THICKNESS AVERAGE	7.870	mils								
	0.200	mm								
IVD WEIGHTS	2.9	mg	5.900	2.100	0.700	7.700	6.000	0.700	0.100	0.100
	TOTALS									
PISTON WEIGHTS	12.377	gm	1.464	1.653	1.604	1.692	1.574	1.501	1.578	1.311
HEAD WEIGHTS	10.330	gm	1.2189	1.3168	1.3479	1.4434	1.3765	1.1652	1.2637	1.1979
TOTAL CCD WEIGHTS	22.707	gm								
RATINGS										
INTAKE RUNNER	9.682	merit	9.710	9.734	9.688	9.688	9.680	9.656	9.632	9.664
VALVE TULIP	9.900	merit	9.900	9.900	9.900	9.900	9.900	9.800	10.000	9.900
INTAKE PORT	9.311	merit	9.288	9.274	9.450	9.300	9.252	9.284	9.336	9.304
PISTON TOP	7.152	merit	7.002	7.323	7.120	7.281	7.069	7.184	7.126	7.108
CHAMBER	7.485	merit	7.588	7.417	7.590	7.531	7.390	7.490	7.426	7.446

GM CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMA	GM1-03-0003	01,02	A	RF-A	ORLANDO	05.19.00	
	AVERAGE	UNITS	1	2	3	4	5	6	7	8
PISTON THICKNESS	9.494	mils	9.830	10.100	9.660	9.340	9.030	9.230	9.780	8.980
	0.241	mm	0.250	0.257	0.245	0.237	0.229	0.234	0.248	0.228
HEAD THICKNESS	6.721	mils	6.510	6.600	7.170	7.870	5.790	6.890	7.010	5.930
	0.171	mm	0.165	0.168	0.182	0.200	0.147	0.175	0.178	0.151
THICKNESS AVERAGE	8.108	mils								
	0.206	mm								
IVD WEIGHTS	12.2	mg	15.800	1.600	6.300	10.400	19.900	27.400	2.200	14.200
	TOTALS									
PISTON WEIGHTS	9.005	gm	1.0934	1.1710	1.1684	1.0113	1.2237	1.2060	1.1148	1.0162
HEAD WEIGHTS	8.980	gm	1.1366	1.1997	1.015	1.1822	1.0078	1.1567	1.1723	1.1096
TOTAL CCD WEIGHTS	17.985	gm								
RATINGS										
INTAKE RUNNER	9.634	merit	9.760	9.732	9.700	9.632	9.519	9.564	9.552	9.616
VALVE TULIP	9.713	merit	9.300	9.900	9.600	9.800	9.700	9.800	9.900	9.700
INTAKE PORT	8.676	merit	8.784	8.653	8.668	8.581	8.720	8.506	8.764	8.735
PISTON TOP	7.005	merit	7.044	7.041	6.968	7.008	7.068	7.036	6.924	6.952
CHAMBER	7.442	merit	7.412	7.340	7.506	7.188	7.622	7.156	7.630	7.684

GM CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			SIMPLE	GM1-04-0004	03,04	B	RF-A	ORLANDO	06.07.00	
	AVERAGE	UNITS	1	2	3	4	5	6	7	8
PISTON THICKNESS	10.325	mils	12.450	9.560	12.200	9.750	10.600	9.240	9.220	9.580
	0.262	mm	0.316	0.243	0.310	0.248	0.269	0.235	0.234	0.243
HEAD THICKNESS	8.568	mils	10.250	7.020	8.080	7.380	11.330	7.550	8.420	8.510
	0.218	mm	0.260	0.178	0.205	0.187	0.288	0.192	0.214	0.216
THICKNESS AVERAGE	9.446	mils								
	0.240	mm								
IVD WEIGHTS	22.2	mg	20.900	14.500	21.100	9.800	39.500	23.100	24.900	24.100
	TOTALS									
PISTON WEIGHTS	8.962	gm	1.1041	1.2668	1.0624	1.1744	1.2033	1.0198	1.0665	1.0648
HEAD WEIGHTS	7.835	gm	1.2778	1.051	0.9057	0.8783	1.1405	0.754	0.9352	0.8925
TOTAL CCD WEIGHTS	16.797	gm								
RATINGS										
INTAKE RUNNER	9.666	merit	9.656	9.648	9.646	9.631	9.728	9.634	9.712	9.672
VALVE TULIP	9.575	merit	9.700	9.800	9.700	9.700	9.200	9.300	9.700	9.500
INTAKE PORT	9.399	merit	9.256	9.377	9.402	9.464	9.496	9.464	9.352	9.379
PISTON TOP	7.467	merit	7.360	7.677	7.323	7.689	7.178	7.690	7.319	7.503
CHAMBER	7.655	merit	7.370	7.682	7.686	7.752	7.603	7.714	7.763	7.666

GM CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMA	GM1-05-0005	01,02	E	RF-A	ORLANDO	06.26.2000	
	AVERAGE	UNITS	1	2	3	4	5	6	7	8
PISTON THICKNESS	9.403	mils	9.750	8.780	9.100	8.550	8.830	10.650	8.610	10.950
	0.239	mm	0.248	0.223	0.231	0.217	0.224	0.271	0.219	0.278
HEAD THICKNESS	9.050	mils	8.630	11.520	7.270	11.750	8.510	7.660	10.310	6.750
	0.230	mm	0.219	0.293	0.185	0.298	0.216	0.195	0.262	0.171
THICKNESS AVERAGE	9.226	mils								
	0.234	mm								
IVD WEIGHTS	845.5	mg	997.100	1070.400	594.000	866.600	792.800	881.900	723.000	838.100
	TOTALS									
PISTON WEIGHTS	6.732	gm	0.9371	0.8456	0.9286	0.8152	0.7378	0.7420	0.8466	0.8794
HEAD WEIGHTS	9.670	gm	1.283	1.4094	1.1492	1.1474	1.1021	1.1859	1.15	1.2432
TOTAL CCD WEIGHTS	16.403	gm								
RATINGS										
INTAKE RUNNER	8.904	merit	8.940	8.900	9.155	9.110	8.850	9.350	8.890	8.040
VALVE TULIP	7.475	merit	7.200	7.400	7.900	7.100	7.500	7.400	7.600	7.700
INTAKE PORT	7.122	merit	7.003	7.720	6.930	7.076	6.915	7.272	6.955	7.106
PISTON TOP	7.543	merit	7.591	7.544	7.550	7.457	7.572	7.488	7.615	7.524
CHAMBER	7.528	merit	7.568	7.590	7.502	7.528	7.478	7.656	7.390	7.511

GM CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			CCDTEST	GM12-06-0006	03,04	A	RF-A	ROBERT	07.13.2000	
	AVERAGE	UNITS	1	2	3	4	5	6	7	8
PISTON THICKNESS	11.831	mils	12.05	11.97	12.01	12.09	11.80	11.45	11.94	11.34
	0.301	mm	0.306	0.304	0.305	0.307	0.300	0.291	0.303	0.288
HEAD THICKNESS	5.850	mils	6.02	5.90	6.26	5.67	4.49	5.62	5.82	7.02
	0.149	mm	0.153	0.150	0.159	0.144	0.114	0.143	0.148	0.178
THICKNESS AVERAGE	8.841	mils								
	0.225	mm								
IVD WEIGHTS	7.0	mg	3.1	6.7	1.1	14.3	8.7	3.0	4.4	15.0
	TOTALS									
PISTON WEIGHTS	7.400	gm	0.8561	0.9006	1.0133	1.0247	0.9261	0.8396	0.8845	0.9553
HEAD WEIGHTS	8.501	gm	1.1393	0.8488	0.8260	1.0781	0.8456	1.2538	1.2252	1.2842
TOTAL CCD WEIGHTS	15.901	gm								
RATINGS										
INTAKE RUNNER	9.046	merit	8.984	9.093	9.065	9.135	9.030	9.102	9.010	8.948
VALVE TULIP	9.5	merit	9.7	9.8	9.5	9.6	9.2	9.5	9.3	9.500
INTAKE PORT	9.136	merit	9.061	9.191	9.132	9.182	9.137	9.068	9.191	9.122
PISTON TOP	7.718	merit	7.792	7.803	7.699	7.730	7.749	7.775	7.376	7.818
CHAMBER	8.172	merit	8.077	8.188	8.160	8.124	8.213	8.169	8.221	8.223

GM CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMA	GM12-07-0007	01,02	D	RF-A	ORLANDO	07.31.2000	
	AVERAGE	UNITS	1	2	3	4	5	6	7	8
PISTON THICKNESS	5.298	mils	4.24	5.70	5.22	6.08	4.93	5.25	5.48	5.48
	0.135	mm	0.108	0.145	0.133	0.154	0.125	0.133	0.139	0.139
HEAD THICKNESS	6.491	mils	8.23	6.36	6.43	6.34	6.51	6.53	5.65	5.88
	0.165	mm	0.209	0.162	0.163	0.161	0.165	0.166	0.144	0.149
THICKNESS AVERAGE	5.894	mils								
	0.150	mm								
IVD WEIGHTS	4.3	mg	3.3	2.9	4.3	7.8	10.2	0.9	0.9	3.8
	TOTALS									
PISTON WEIGHTS	12.042	gm	1.3865	1.5699	1.3977	1.8161	1.2852	1.5066	1.3834	1.6968
HEAD WEIGHTS	9.408	gm	1.2125	1.2100	1.1040	1.2918	1.1154	1.2162	1.1075	1.1503
TOTAL CCD WEIGHTS	21.450	gm								
RATINGS										
INTAKE RUNNER	9.715	merit	9.650	9.752	9.712	9.716	9.710	9.740	9.688	9.752
VALVE TULIP	9.588	merit	9.6	9.7	9.5	9.7	9.0	9.5	9.9	9.800
INTAKE PORT	9.546	merit	9.604	9.580	9.472	9.526	9.606	9.540	9.434	9.602
PISTON TOP	6.960	merit	6.992	6.974	6.792	6.976	7.050	6.988	7.013	6.896
CHAMBER	7.380	merit	7.524	7.335	7.545	7.265	7.322	7.292	7.328	7.430

GM CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			SIMPLE	GM12-08-0008	03, 04	C	RF-A	ORLANDO	08.20.2000	
	AVERAGE	UNITS	1	2	3	4	5	6	7	8
PISTON THICKNESS	4.119	mils	4.02	3.98	4.75	3.92	4.11	4.02	4.27	3.88
	0.105	mm	0.102	0.101	0.121	0.100	0.104	0.102	0.108	0.099
HEAD THICKNESS	5.358	mils	5.30	4.86	5.67	5.96	5.37	5.18	5.39	5.13
	0.136	mm	0.135	0.123	0.144	0.151	0.136	0.132	0.137	0.130
THICKNESS AVERAGE	4.738	mils								
	0.120	mm								
IVD WEIGHTS	255.9	mg	180.7	161.6	159.4	214.9	378.2	368.7	279.2	304.8
	TOTALS									
PISTON WEIGHTS	8.562	gm	1.2635	1.1119	1.3182	0.7434	1.2285	0.8262	1.2702	0.7998
HEAD WEIGHTS	8.208	gm	0.9968	1.0031	1.0302	1.1302	1.0099	0.9409	1.0061	1.0909
TOTAL CCD WEIGHTS	16.770	gm								
RATINGS										
INTAKE RUNNER	8.578	merit	8.444	8.630	8.394	8.635	8.587	8.742	8.458	8.734
VALVE TULIP	7.738	merit	7.7	8.0	8.1	7.8	7.2	7.6	7.7	7.800
INTAKE PORT	7.362	merit	7.720	7.881	7.380	6.948	7.097	7.286	7.266	7.318
PISTON TOP	7.841	merit	7.980	7.780	7.977	7.715	7.950	7.775	7.805	7.745
CHAMBER	7.712	merit	7.587	7.800	7.554	7.750	7.721	7.795	7.656	7.835

GM CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMA	GM12-09-0009	01, 02	C	RF-A	ROBERT	09.09.2000	
	AVERAGE	UNITS	1	2	3	4	5	6	7	8
PISTON THICKNESS	3.971	mils	4.01	3.94	3.62	3.99	3.57	4.76	3.34	4.54
	0.101	mm	0.102	0.100	0.092	0.101	0.091	0.121	0.085	0.115
HEAD THICKNESS	6.643	mils	7.41	5.88	7.91	6.69	5.62	7.26	5.85	6.52
	0.169	mm	0.188	0.149	0.201	0.170	0.143	0.184	0.149	0.166
THICKNESS AVERAGE	5.307	mils								
	0.135	mm								
IVD WEIGHTS	355.4	mg	413.7	238.5	438.0	281.2	527.8	346.3	280.5	316.8
	TOTALS									
PISTON WEIGHTS	8.024	gm	1.0441	1.0246	0.9762	1.1182	0.9303	1.0996	0.8524	0.9786
HEAD WEIGHTS	8.347	gm	1.1553	1.0593	0.9919	1.0349	0.9349	1.0009	0.964	1.2058
TOTAL CCD WEIGHTS	16.371	gm								
RATINGS										
INTAKE RUNNER	8.976	merit	9.400	9.200	9.440	8.676	8.726	8.767	8.633	8.962
VALVE TULIP	7.850	merit	7.5	8.3	7.6	8.2	7.5	7.7	8.1	7.900
INTAKE PORT	7.461	merit	7.154	7.626	7.367	7.197	7.726	7.309	7.990	7.322
PISTON TOP	7.652	merit	7.780	7.600	7.695	7.525	7.580	7.670	7.610	7.755
CHAMBER	7.937	merit	7.872	7.782	8.082	8.031	7.973	7.916	7.945	7.891

GM CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			SIMPLE	GM12-10-0010	03, 04	E	RF-A	ROBERT	09.26.2000	
	AVERAGE	UNITS	1	2	3	4	5	6	7	8
PISTON THICKNESS	3.990	mils	3.99	3.74	4.01	4.36	3.62	4.22	3.86	4.12
	0.101	mm	0.101	0.095	0.102	0.111	0.092	0.107	0.098	0.105
HEAD THICKNESS	6.490	mils	6.18	6.66	6.74	7.65	5.98	6.55	5.81	6.35
	0.165	mm	0.157	0.169	0.171	0.194	0.152	0.166	0.148	0.161
THICKNESS AVERAGE	5.240	mils								
	0.133	mm								
IVD WEIGHTS	661.3	mg	765.3	710.1	611.1	773.7	550.1	616.0	591.2	672.7
	TOTALS									
PISTON WEIGHTS	8.719	gm	1.0842	1.0887	1.1102	1.1892	1.0173	1.2038	0.9469	1.0791
HEAD WEIGHTS	10.046	gm	1.1950	1.3289	1.2516	1.1323	1.1627	1.4289	1.2161	1.3306
TOTAL CCD WEIGHTS	18.766	gm								
RATINGS										
INTAKE RUNNER	8.635	merit	9.291	8.325	9.124	8.385	8.656	8.227	8.777	8.297
VALVE TULIP	7.688	merit	8.0	7.7	7.9	7.6	7.5	7.8	7.4	7.6
INTAKE PORT	7.109	merit	7.110	7.160	7.010	7.191	7.103	6.960	7.204	7.135
PISTON TOP	8.047	merit	8.007	8.035	8.081	7.986	8.087	8.102	8.027	8.050
CHAMBER	8.009	merit	8.059	8.025	7.928	7.992	7.948	8.055	8.087	7.981

GM CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			SIMPLE	GM13-01-0001	01,02	A	RF-A	ORLANDO	03.03.2000	
	AVERAGE	UNITS	1	2	3	4	5	6	7	8
PISTON THICKNESS	4.148	mils	5.220	3.900	4.290	3.910	4.280	3.950	3.770	3.860
	0.105	mm	0.133	0.099	0.109	0.099	0.109	0.100	0.096	0.098
HEAD THICKNESS	4.694	mils	5.090	4.830	4.700	5.070	4.060	4.680	4.470	4.650
	0.119	mm	0.129	0.123	0.119	0.129	0.103	0.119	0.114	0.118
THICKNESS AVERAGE	4.421	mils								
	0.112	mm								
IVD WEIGHTS	10.9	mg	14.400	10.300	9.400	5.700	5.100	20.500	16.000	6.000
	TOTALS									
PISTON WEIGHTS	9.178	gm	1.187	1.080	1.192	1.115	1.217	0.993	1.259	1.136
HEAD WEIGHTS	10.017	gm	1.2592	1.3056	1.2599	1.3994	1.1486	1.2104	1.2129	1.2205
TOTAL CCD WEIGHTS	19.195	gm								
RATINGS										
INTAKE RUNNER	9.404	merit	9.446	9.352	9.436	9.428	9.384	9.396	9.392	9.400
VALVE TULIP	9.825	merit	9.800	9.900	9.900	9.800	10.000	9.600	9.700	9.900
INTAKE PORT	9.025	merit	9.028	9.056	9.012	9.000	9.044	9.056	9.056	8.944
PISTON TOP	7.844	merit	7.725	7.975	7.803	7.994	7.460	7.930	7.918	7.944
CHAMBER	7.808	merit	7.752	7.766	7.754	7.758	7.966	7.890	7.820	7.758

GM CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMA	GM2-02-0002A	03,04	B	RF-A	ORLANDO	05.19.00	
	AVERAGE	UNITS	1	2	3	4	5	6	7	8
PISTON THICKNESS	7.605	mils	6.090	11.140	5.440	9.660	4.250	9.350	5.330	9.580
	0.193	mm	0.155	0.283	0.138	0.245	0.108	0.237	0.135	0.243
HEAD THICKNESS	6.105	mils	6.050	6.010	5.680	7.250	5.200	5.500	6.570	6.580
	0.155	mm	0.154	0.153	0.144	0.184	0.132	0.140	0.167	0.167
THICKNESS AVERAGE	6.855	mils								
	0.174	mm								
IVD WEIGHTS	30.1	mg	18.200	21.100	26.600	38.800	30.300	29.600	42.800	33.300
	TOTALS									
PISTON WEIGHTS	10.011	gm	1.1959	1.3615	1.2491	1.3053	1.2225	1.1510	1.2167	1.3090
HEAD WEIGHTS	7.166	gm	0.8573	0.8337	0.8849	0.8828	0.8252	0.9159	0.8076	1.1586
TOTAL CCD WEIGHTS	17.177	gm								
RATINGS										
INTAKE RUNNER	9.707	merit	9.844	9.660	9.672	9.660	9.664	9.650	9.860	9.644
VALVE TULIP	9.425	merit	9.600	9.500	9.500	9.400	9.300	9.400	9.300	9.400
INTAKE PORT	9.255	merit	9.270	9.188	9.226	9.252	9.334	9.206	9.260	9.302
PISTON TOP	7.084	merit	7.199	7.012	7.098	7.020	7.032	7.132	7.120	7.058
CHAMBER	7.433	merit	7.369	7.431	7.503	7.388	7.396	7.418	7.578	7.380

GM CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			SIMPLE	GM2-03-0003	01,02	E	RF-A	ORLANDO	06.05.00	
	AVERAGE	UNITS	1	2	3	4	5	6	7	8
PISTON THICKNESS	11.709	mils	11.450	12.390	11.690	12.320	11.400	11.600	10.940	11.880
	0.297	mm	0.291	0.315	0.297	0.313	0.290	0.295	0.278	0.302
HEAD THICKNESS	6.626	mils	6.710	6.610	6.550	6.830	7.480	6.490	6.340	6.000
	0.168	mm	0.170	0.168	0.166	0.173	0.190	0.165	0.161	0.152
THICKNESS AVERAGE	9.168	mils								
	0.233	mm								
IVD WEIGHTS	476.2	mg	492.500	527.800	407.000	561.200	400.000	489.700	489.600	441.900
	TOTALS									
PISTON WEIGHTS	9.619	gm	1.2786	1.1961	1.1954	1.2635	1.1609	1.1426	1.1020	1.2802
HEAD WEIGHTS	7.462	gm	1.1946	0.8384	0.9375	0.8262	0.978	0.8936	0.8687	0.9247
TOTAL CCD WEIGHTS	17.081	gm								
RATINGS										
INTAKE RUNNER	8.373	merit	8.325	8.370	8.225	8.885	8.315	8.235	8.260	8.370
VALVE TULIP	7.813	merit	7.900	7.700	7.900	7.600	8.000	7.800	7.800	7.800
INTAKE PORT	7.404	merit	7.476	7.280	7.452	7.568	7.404	7.252	7.560	7.236
PISTON TOP	7.629	merit	7.738	7.570	7.716	7.626	7.618	7.602	7.572	7.592
CHAMBER	7.902	merit	7.894	7.932	7.942	7.868	7.852	7.918	7.912	7.898

GM CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMA	GM2-04-0004	03,04	E	RF-A	ORLANDO	06.26.2000	
	AVERAGE	UNITS	1	2	3	4	5	6	7	8
PISTON THICKNESS	10.819	mils	10.200	10.140	10.600	10.960	9.420	13.300	9.690	12.240
	0.275	mm	0.259	0.258	0.269	0.278	0.239	0.338	0.246	0.311
HEAD THICKNESS	7.913	mils	7.870	8.210	4.250	7.990	6.530	12.450	6.080	9.920
	0.201	mm	0.200	0.209	0.108	0.203	0.166	0.316	0.154	0.252
THICKNESS AVERAGE	9.366	mils								
	0.238	mm								
IVD WEIGHTS	867.2	mg	873.800	1074.400	703.900	929.500	808.700	733.500	793.400	1020.700
	TOTALS									
PISTON WEIGHTS	6.732	gm	0.7544	0.7245	0.9417	0.8242	0.6920	1.2172	0.5762	1.0018
HEAD WEIGHTS	8.211	gm	1.107	0.9929	1.0438	0.9635	0.7851	1.3656	0.7879	1.1647
TOTAL CCD WEIGHTS	14.943	gm								
RATINGS										
INTAKE RUNNER	9.272	merit	9.412	8.992	9.412	9.318	9.302	9.070	9.382	9.284
VALVE TULIP	7.275	merit	7.300	7.200	7.600	7.400	7.500	6.900	7.300	7.000
INTAKE PORT	7.274	merit	7.011	7.432	7.142	7.411	7.060	7.362	7.285	7.490
PISTON TOP	7.402	merit	7.546	7.522	7.547	7.425	7.443	7.026	7.468	7.235
CHAMBER	7.651	merit	7.740	7.624	7.724	7.695	7.784	7.490	7.712	7.435

GM CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			CCDTEST	GM13-05-0005	01,02	D	RF-A	ORLANDO	07.16.2000	
	AVERAGE	UNITS	1	2	3	4	5	6	7	8
PISTON THICKNESS	16.354	mils	15.49	17.71	16.61	17.67	15.14	16.09	15.93	16.19
	0.415	mm	0.393	0.450	0.422	0.449	0.385	0.409	0.405	0.411
HEAD THICKNESS	11.808	mils	9.71	13.25	11.47	13.84	11.46	11.33	11.20	12.20
	0.300	mm	0.247	0.337	0.291	0.352	0.291	0.288	0.284	0.310
THICKNESS AVERAGE	14.081	mils								
	0.358	mm								
IVD WEIGHTS	66.7	mg	44.3	39.0	90.4	1.2	146.9	36.9	100.3	74.2
	TOTALS									
PISTON WEIGHTS	15.200	gm	1.7215	1.9846	2.0796	2.1824	1.7892	1.7911	1.7176	1.9342
HEAD WEIGHTS	14.364	gm	1.7013	1.6886	1.8883	2.0107	1.8429	1.6742	1.7364	1.822
TOTAL CCD WEIGHTS	29.565	gm								
RATINGS										
INTAKE RUNNER	9.483	merit	9.740	8.710	9.672	9.704	9.696	9.152	9.728	9.458
VALVE TULIP	8.2	merit	8.3	8.1	7.9	8.0	8.2	8.3	8.3	8.200
INTAKE PORT	9.357	merit	9.514	9.560	9.272	9.240	9.205	9.484	9.344	9.236
PISTON TOP	6.995	merit	6.959	7.018	6.876	7.052	6.925	6.966	7.064	7.101
CHAMBER	7.055	merit	7.049	6.998	7.057	7.106	7.043	6.982	7.126	7.080

GM CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMA	GM13-06-0006	03,04	D	RF-A	ORLANDO	08.01.2000	
	AVERAGE	UNITS	1	2	3	4	5	6	7	8
PISTON THICKNESS	8.231	mils	7.18	7.63	7.58	12.97	7.31	7.37	7.58	8.23
	0.209	mm	0.182	0.194	0.193	0.329	0.186	0.187	0.193	0.209
HEAD THICKNESS	8.629	mils	8.86	8.30	9.11	8.26	9.02	7.99	8.45	9.04
	0.219	mm	0.225	0.211	0.231	0.210	0.229	0.203	0.215	0.230
THICKNESS AVERAGE	8.430	mils								
	0.214	mm								
IVD WEIGHTS	17.7	mg	29.7	9.1	0.1	1.8	13.4	39.2	39.9	8.4
	TOTALS									
PISTON WEIGHTS	15.408	gm	1.7519	2.0569	1.8186	2.0605	1.8113	2.0557	1.7449	2.1082
HEAD WEIGHTS	14.552	gm	1.9990	1.7107	1.8286	1.8055	1.7393	1.7553	1.8530	1.8602
TOTAL CCD WEIGHTS	29.960	gm								
RATINGS										
INTAKE RUNNER	9.636	merit	9.532	9.680	9.650	9.690	9.650	9.520	9.650	9.712
VALVE TULIP	9.263	merit	8.8	9.3	9.7	9.6	9.2	9.1	9.2	9.2
INTAKE PORT	9.506	merit	9.368	9.512	9.560	9.552	9.584	9.440	9.544	9.488
PISTON TOP	7.331	merit	7.295	7.316	7.225	7.638	7.263	7.331	7.190	7.388
CHAMBER	7.252	merit	7.232	7.180	7.183	7.295	7.305	7.280	7.300	7.240

GM CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			SIMPLE	GM13-07-0007	01, 02	C	RF-A	ORLANDO	08.21.2000	
	AVERAGE	UNITS	1	2	3	4	5	6	7	8
PISTON THICKNESS	4.379	mils	4.19	4.92	4.37	4.50	3.95	4.43	4.21	4.46
	0.111	mm	0.106	0.125	0.111	0.114	0.100	0.113	0.107	0.113
HEAD THICKNESS	5.678	mils	6.56	6.37	6.94	5.15	5.21	4.68	5.53	4.98
	0.144	mm	0.167	0.162	0.176	0.131	0.132	0.119	0.140	0.126
THICKNESS AVERAGE	5.028	mils								
	0.128	mm								
IVD WEIGHTS	212.2	mg	168.6	211.0	253.0	169.2	350.9	151.5	201.8	191.7
	TOTALS									
PISTON WEIGHTS	7.817	gm	1.0328	1.0062	1.0835	0.8520	1.0800	0.8661	1.0171	0.8789
HEAD WEIGHTS	8.441	gm	1.0713	1.0714	1.0098	1.0487	1.0963	1.0484	1.0650	1.0303
TOTAL CCD WEIGHTS	16.258	gm								
RATINGS										
INTAKE RUNNER	8.375	merit	8.792	8.156	8.431	8.548	8.416	8.287	8.214	8.155
VALVE TULIP	8.413	merit	8.4	8.4	8.3	8.6	7.7	8.7	8.7	8.5
INTAKE PORT	7.558	merit	7.625	7.649	7.434	7.659	7.557	7.389	7.520	7.630
PISTON TOP	7.436	merit	7.440	7.470	7.320	7.490	7.460	7.485	7.330	7.495
CHAMBER	7.456	merit	7.550	7.450	7.570	7.522	7.510	7.411	7.055	7.577

GM CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMA	GM13-08-0008	03, 04	A	RF-A	ORLANDO	09.13.2000	
	AVERAGE	UNITS	1	2	3	4	5	6	7	8
PISTON THICKNESS	5.121	mils	5.86	5.07	5.08	4.97	4.76	4.63	5.97	4.63
	0.130	mm	0.149	0.129	0.129	0.126	0.121	0.118	0.152	0.118
HEAD THICKNESS	6.128	mils	6.34	5.94	6.27	5.97	4.99	5.93	7.55	6.03
	0.156	mm	0.161	0.151	0.159	0.152	0.127	0.151	0.192	0.153
THICKNESS AVERAGE	5.624	mils								
	0.143	mm								
IVD WEIGHTS	6.6	mg	7.7	0.2	8.7	4.0	9.2	1.7	14.5	7.0
	TOTALS									
PISTON WEIGHTS	9.139	gm	1.3318	1.2282	1.1515	1.0614	1.0886	0.9420	1.3684	0.9668
HEAD WEIGHTS	10.106	gm	1.6740	1.1822	1.1587	1.1627	1.1728	1.0054	1.6711	1.0795
TOTAL CCD WEIGHTS	19.245	gm								
RATINGS										
INTAKE RUNNER	9.328	merit	9.350	9.480	9.290	9.250	9.290	9.280	9.280	9.400
VALVE TULIP	9.550	merit	9.4	9.6	9.5	9.4	9.6	9.8	9.6	9.5
INTAKE PORT	8.652	merit	8.650	8.415	8.500	8.864	8.740	8.620	8.800	8.630
PISTON TOP	7.110	merit	7.105	7.081	7.295	7.169	7.168	6.960	7.012	7.086
CHAMBER	7.195	merit	7.221	7.106	7.305	7.199	7.267	7.060	7.168	7.234

GM CCD DATA										
PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			SIMPLE	GM13-09-000	01, 02	B	RF-A	ORLANDO	10.05.2000	
	AVERAGE	UNITS	1	2	3	4	5	6	7	8
PISTON THICKNESS	5.264	mils	5.25	5.27	5.59	5.46	5.48	4.80	5.33	4.93
	0.134	mm	0.133	0.134	0.142	0.139	0.139	0.122	0.135	0.125
HEAD THICKNESS	5.065	mils	4.98	4.49	5.11	4.99	4.54	6.06	4.42	5.93
	0.129	mm	0.126	0.114	0.130	0.127	0.115	0.154	0.112	0.151
THICKNESS AVERAGE	5.164	mils								
	0.131	mm								
IVD WEIGHTS	2.9	mg	0.1	0.6	0.1	0.9	2.3	17.7	0.7	0.8
	TOTALS									
PISTON WEIGHTS	9.288	gm	1.1725	1.2534	1.2255	1.1410	1.2025	1.1016	1.1114	1.0800
HEAD WEIGHTS	7.794	gm	0.9554	0.8063	0.9727	0.9370	0.9289	1.1505	0.9381	1.1047
TOTAL CCD WEIGHTS	17.082	gm								
RATINGS										
INTAKE RUNNER	9.614	merit	9.660	9.614	9.620	9.635	9.600	9.632	9.480	9.672
VALVE TULIP	9.750	merit	10.0	9.5	9.9	9.4	9.9	9.7	10.0	9.6
INTAKE PORT	9.474	merit	9.236	9.480	9.440	9.610	9.402	9.630	9.400	9.592
PISTON TOP	7.329	merit	7.244	7.172	7.304	7.464	7.181	7.631	7.395	7.237
CHAMBER	7.747	merit	7.587	7.572	7.647	7.682	7.588	8.223	7.506	8.174

GM CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMA	GM13-10-0010	03, 04	C	RF-A	ROBERT	10.20.2000	
	AVERAGE	UNITS	1	2	3	4	5	6	7	8
PISTON THICKNESS	4.150	mils	4.08	4.13	4.23	4.16	4.03	4.00	4.06	4.51
	0.105	mm	0.104	0.105	0.107	0.106	0.102	0.102	0.103	0.115
HEAD THICKNESS	5.051	mils	4.94	5.44	4.92	5.30	4.74	4.88	4.98	5.21
	0.128	mm	0.125	0.138	0.125	0.135	0.120	0.124	0.126	0.132
THICKNESS AVERAGE	4.601	mils								
	0.117	mm								
IVD WEIGHTS	43.3	mg	29.3	24.0	13.2	45.4	101.9	44.7	33.5	54.7
	TOTALS									
PISTON WEIGHTS	8.183	gm	1.0852	1.1071	1.0872	0.9847	1.1010	0.9661	0.8449	1.0072
HEAD WEIGHTS	9.430	gm	1.1235	1.2254	1.1622	1.1845	1.1578	1.1217	1.2227	1.2320
TOTAL CCD WEIGHTS	17.613	gm								
RATINGS										
INTAKE RUNNER	9.166	merit	9.189	9.234	9.134	9.196	9.130	9.182	9.121	9.142
VALVE TULIP	8.863	merit	9.0	8.9	9.1	8.8	8.7	8.6	8.8	9.0
INTAKE PORT	8.097	merit	8.132	8.343	7.994	8.172	7.960	8.104	7.907	8.166
PISTON TOP	7.979	merit	7.972	8.073	7.952	8.032	7.993	7.952	7.808	8.046
CHAMBER	8.217	merit	8.266	8.258	8.278	8.282	8.161	8.224	8.068	8.198

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMA	DC2-01-0001	1	D	RF-A	ORLANDO	03.08.2000	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	9.527	mils	9.186		10.576		8.972		9.373	
	0.242	mm	0.233		0.269		0.228		0.238	
HEAD THICKNESS	9.843	mils	11.022		10.968		7.170		10.212	
	0.250	mm	0.280		0.279		0.182		0.259	
THICKNESS AVERAGE	9.685	mils								
	0.246	mm								
IVD WEIGHTS	4.8	mg	9.1	4.4	2.1	3.7	4.4	5.9	5.2	3.6
	TOTALS									
PISTON WEIGHTS	3.816	gm	0.9893		0.9652		0.8951		0.9665	
HEAD WEIGHTS	3.586	gm	0.9325		1.0167		0.7068		0.9303	
TOTAL CCD WEIGHTS	7.402	gm								
RATINGS										
INTAKE RUNNER	9.534	merit	9.525		9.510		9.545		9.555	
VALVE TULIP	9.350	merit	9.150		9.650		9.300		9.300	
INTAKE PORT	9.608	merit	9.630	9.61	9.620	9.61	9.600	9.63	9.590	9.575
PISTON TOP	6.893	merit	6.852		6.690		7.121		6.908	
CHAMBER	6.950	merit	6.875		6.917		7.086		6.920	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			SIMPLE	DC2-02-0002	2	A	RF-A	ORLANDO	06.17.2000	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	10.220	mils	11.050		10.100		9.750		9.980	
	0.260	mm	0.281		0.257		0.248		0.253	
HEAD THICKNESS	17.725	mils	18.060		18.750		16.370		17.720	
	0.450	mm	0.459		0.476		0.416		0.450	
THICKNESS AVERAGE	13.973	mils								
	0.355	mm								
IVD WEIGHTS	7.5	mg	3.8	5.7	7.8	6.2	8.4	7.0	11.8	9.3
	TOTALS									
PISTON WEIGHTS	4.227	gm	1.1928		1.0331		1.0065		0.9948	
HEAD WEIGHTS	3.486	gm	1.0315		0.8288		0.8713		0.7547	
TOTAL CCD WEIGHTS	7.714	gm								
RATINGS										
INTAKE RUNNER	9.490	merit	9.556		9.242		9.492		9.670	
VALVE TULIP	9.363	merit	9.400		9.350		9.250		9.450	
INTAKE PORT	9.516	merit	9.506	9.392	9.464	9.582	9.495	9.582	9.533	9.577
PISTON TOP	6.675	merit	6.870		6.695		6.570		6.565	
CHAMBER	6.808	merit	6.735		6.890		6.860		6.745	

DC CCD DATA										
PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMA	DC1-03-0003	2	C	RF-A	ORLANDO	07.28.00	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	4.040	mils	4.157		3.993		3.998		4.011	
	0.103	mm	0.106		0.101		0.102		0.102	
HEAD THICKNESS	4.973	mils	4.987		4.724		5.801		4.378	
	0.126	mm	0.127		0.120		0.147		0.111	
THICKNESS AVERAGE	4.506	mils								
	0.114	mm								
IVD WEIGHTS	543.3	mg	579.7	559.8	449.7	1133.6	1.8	448.4	440.4	732.9
	TOTALS									
PISTON WEIGHTS	3.709	gm	0.9495		0.9123		0.9381		0.9091	
HEAD WEIGHTS	3.168	gm	0.8000		0.7549		0.8462		0.7665	
TOTAL CCD WEIGHTS	6.877	gm								
RATINGS										
INTAKE RUNNER	9.098	merit	9.080		9.100		9.140		9.070	
VALVE TULIP	6.900	merit	6.900		6.900		6.900		6.900	
INTAKE PORT	8.765	merit	8.750	8.532	8.890	8.575	8.800	9.116	8.552	8.908
PISTON TOP	8.112	merit	8.230		8.033		8.036		8.150	
CHAMBER	7.352	merit	7.362		7.387		7.334		7.325	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			SIMPLE	DC2-04-0004A	2	D	RF-A	ORLANDO	09.16.2000	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	6.087	mils	7.362		5.683		5.170		6.131	
	0.155	mm	0.187		0.144		0.131		0.156	
HEAD THICKNESS	7.510	mils	6.927		8.024		7.617		7.471	
	0.191	mm	0.176		0.204		0.193		0.190	
THICKNESS AVERAGE	6.798	mils								
	0.173	mm								
IVD WEIGHTS	4.7	mg	5.2	8.8	4.8	1.2	3.5	3.0	7.4	3.7
	TOTALS									
PISTON WEIGHTS	4.402	gm	1.0050		1.0773		1.1210		1.1982	
HEAD WEIGHTS	4.141	gm	1.0694		1.0377		0.9414		1.0927	
TOTAL CCD WEIGHTS	8.543	gm								
RATINGS										
INTAKE RUNNER	9.497	merit	9.540		9.468		9.495		9.486	
VALVE TULIP	8.325	merit	8.300		8.300		8.450		8.250	
INTAKE PORT	9.654	merit	9.658	9.625	9.664	9.67	9.670	9.67	9.631	9.643
PISTON TOP	7.388	merit	7.492		7.405		7.272		7.381	
CHAMBER	6.923	merit	6.912		6.875		7.015		6.890	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMA	DC2-05-0005	2	B	RF-A	ORLANDO	10.09.2000	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	4.939	mils	4.899		5.547		4.368		4.943	
	0.125	mm	0.124		0.141		0.111		0.126	
HEAD THICKNESS	4.829	mils	5.808		5.808		3.985		3.715	
	0.123	mm	0.148		0.148		0.101		0.094	
THICKNESS AVERAGE	4.884	mils								
	0.124	mm								
IVD WEIGHTS	4.4	mg	3.1	0.5	0.8	1.6	4.6	8.6	8.8	7.0
	TOTALS									
PISTON WEIGHTS	3.333	gm	0.8619		0.8915		0.8006		0.7787	
HEAD WEIGHTS	2.988	gm	0.6958		0.7676		0.7159		0.8089	
TOTAL CCD WEIGHTS	6.321	gm								
RATINGS										
INTAKE RUNNER	9.670	merit	9.650		9.680		9.650		9.700	
VALVE TULIP	9.463	merit	9.700		9.650		9.300		9.200	
INTAKE PORT	9.771	merit	9.772	9.6	9.787	9.792	9.816	9.81	9.822	9.769
PISTON TOP	7.401	merit	7.330		7.465		7.407		7.400	
CHAMBER	7.507	merit	7.517		7.535		7.542		7.434	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			SIMPLE	DC2-06-0006	1	C	RF-A	ORLANDO	10.24.2000	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	6.047	mils	6.577		6.867		5.096		5.646	
	0.154	mm	0.167		0.174		0.129		0.143	
HEAD THICKNESS	4.414	mils	2.701		3.312		6.838		4.806	
	0.112	mm	0.069		0.084		0.174		0.122	
THICKNESS AVERAGE	5.230	mils								
	0.133	mm								
IVD WEIGHTS	28.8	mg	34.0	11.1	12.4	13.8	16.6	12.1	12.6	117.6
	TOTALS									
PISTON WEIGHTS	4.057	gm	1.1079		1.0983		0.9067		0.9445	
HEAD WEIGHTS	3.514	gm	0.9276		1.0021		0.7212		0.8626	
TOTAL CCD WEIGHTS	7.571	gm								
RATINGS										
INTAKE RUNNER	9.352	merit	9.328		9.264		9.224		9.590	
VALVE TULIP	8.750	merit	8.650		8.950		9.050		8.350	
INTAKE PORT	8.866	merit	8.992	8.769	8.846	8.665	8.970	8.958	8.847	8.88
PISTON TOP	7.945	merit	8.140		7.845		7.890		7.905	
CHAMBER	7.322	merit	7.441		7.375		7.215		7.255	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMA	DC2-07-0007	2	A	RF-A	ORLANDO	11.08.2000	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	5.393	mils	5.472		6.085		4.780		5.233	
	0.137	mm	0.139		0.155		0.121		0.133	
HEAD THICKNESS	2.314	mils	2.337		2.448		2.305		2.167	
	0.059	mm	0.059		0.062		0.059		0.055	
THICKNESS AVERAGE	3.853	mils								
	0.098	mm								
IVD WEIGHTS	9.6	mg	0.5	1.2	1.6	2.8	32.0	0.4	1.5	36.7
	TOTALS									
PISTON WEIGHTS	4.165	gm	1.0384		1.0857		0.9708		1.0696	
HEAD WEIGHTS	3.111	gm	0.7906		0.7933		0.7232		0.8037	
TOTAL CCD WEIGHTS	7.275	gm								
RATINGS										
INTAKE RUNNER	9.713	merit	9.680		9.704		9.675		9.792	
VALVE TULIP	9.625	merit	9.750		9.650		9.550		9.550	
INTAKE PORT	9.423	merit	9.573	9.499	9.555	9.538	9.594	9.585	8.444	9.593
PISTON TOP	7.466	merit	7.680		7.398		7.462		7.324	
CHAMBER	7.602	merit	7.643		7.601		7.592		7.573	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			SIMPLE	DC2-08-0008	3	E	RF-A	ROBERT	12/27/2000	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	4.997	mils	5.431		5.399		4.340		4.819	
	0.127	mm	0.138		0.137		0.110		0.122	
HEAD THICKNESS	7.551	mils	7.836		7.388		7.326		7.652	
	0.192	mm	0.199		0.188		0.186		0.194	
THICKNESS AVERAGE	6.274	mils								
	0.159	mm								
IVD WEIGHTS	497.0	mg	537.9	591.6	464.7	509.1	461.7	439.6	479.0	492.1
	TOTALS									
PISTON WEIGHTS	3.706	gm	1.0124		0.9314		0.9035		0.8586	
HEAD WEIGHTS	3.684	gm	0.9151		1.0157		0.9005		0.8529	
TOTAL CCD WEIGHTS	7.390	gm								
RATINGS										
INTAKE RUNNER	9.114	merit	8.979		9.222		9.054		9.201	
VALVE TULIP	6.675	merit	6.550		6.750		6.850		6.550	
INTAKE PORT	7.605	merit	7.556	7.793	7.600	7.558	7.620	7.71	7.457	7.544
PISTON TOP	7.771	merit	7.793		7.668		7.782		7.840	
CHAMBER	7.828	merit	7.964		7.778		7.761		7.808	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMA	DC2-09-0009	2	E	RF-A	ROBERT	01.15.2001	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	3.755	mils	4.241		4.099		4.059		2.621	
	0.095	mm	0.108		0.104		0.103		0.067	
HEAD THICKNESS	5.296	mils	5.936		4.230		5.587		5.432	
	0.135	mm	0.151		0.107		0.142		0.138	
THICKNESS AVERAGE	4.526	mils								
	0.115	mm								
IVD WEIGHTS	522.2	mg	653.4	580.3	443.4	537.5	481.7	389.7	500.0	591.8
	TOTALS									
PISTON WEIGHTS	2.377	gm	0.5493		0.4008		0.6608		0.7658	
HEAD WEIGHTS	3.425	gm	0.8626		1.1420		0.9288		0.4915	
TOTAL CCD WEIGHTS	5.802	gm								
RATINGS										
INTAKE RUNNER	8.721	merit	9.136		8.868		8.092		8.788	
VALVE TULIP	5.863	merit	5.700		5.800		5.900		6.050	
INTAKE PORT	7.901	merit	8.042	8.181	7.833	7.945	7.853	7.805	7.752	7.799
PISTON TOP	8.403	merit	8.124		8.570		8.569		8.350	
CHAMBER	7.807	merit	7.984		7.847		7.741		7.654	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			SIMPLE	DC2-10-0010	3	B	RF-A	ROBERT	02.06.01	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	6.623	mils	6.451		7.788		6.077		6.177	
	0.168	mm	0.164		0.198		0.154		0.157	
HEAD THICKNESS	6.562	mils	5.976		6.222		6.631		7.419	
	0.167	mm	0.152		0.158		0.168		0.188	
THICKNESS AVERAGE	6.593	mils								
	0.167	mm								
IVD WEIGHTS	1.4	mg	0.7	0.7	0.8	1.5	1.9	2.7	2.7	0.0
	TOTALS									
PISTON WEIGHTS	4.401	gm	1.0215		1.1767		1.1453		1.0576	
HEAD WEIGHTS	2.904	gm	0.7179		0.6959		0.6907		0.7999	
TOTAL CCD WEIGHTS	7.306	gm								
RATINGS										
INTAKE RUNNER	9.724	merit	9.696		9.758		9.728		9.712	
VALVE TULIP	9.763	merit	9.800		9.800		9.800		9.650	
INTAKE PORT	9.748	merit	9.724	9.778	9.752	9.788	9.778	9.763	9.692	9.708
PISTON TOP	7.047	merit	6.963		7.040		7.179		7.004	
CHAMBER	7.154	merit	7.213		7.129		7.100		7.173	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MMASOAK	DC2-11-0011	5	D	RF-A	GARCIA	06.15.2001	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	5.645	mils	6.564		5.277		4.391		6.349	
	0.143	mm	0.167		0.134		0.112		0.161	
HEAD THICKNESS	5.266	mils	4.846		4.784		5.310		6.123	
	0.134	mm	0.123		0.122		0.135		0.156	
THICKNESS AVERAGE	5.456	mils								
	0.139	mm								
IVD WEIGHTS	2.3	mg	2.2	2.0	0.8	2.3	1.6	6.4	2.5	0.9
	TOTALS									
PISTON WEIGHTS	4.532	gm	1.3145		1.0791		0.9081		1.2306	
HEAD WEIGHTS	4.004	gm	1.1202		1.0543		0.8021		1.0277	
TOTAL CCD WEIGHTS	8.537	gm								
RATINGS										
INTAKE RUNNER	9.769	merit	9.795		9.755		9.745		9.780	
VALVE TULIP	9.450	merit	9.400		9.600		9.550		9.250	
INTAKE PORT	9.751	merit	9.760	9.74	9.780	9.695	9.760	9.75	9.740	9.78
PISTON TOP	7.964	merit	7.865		8.126		8.062		7.803	
CHAMBER	7.705	merit	7.622		7.766		7.692		7.740	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MMASOAK	DC2-11-0011	5	D	RF-A	GARCIA	06.15.2001	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	5.645	mils	6.564		5.277		4.391		6.349	
	0.143	mm	0.167		0.134		0.112		0.161	
HEAD THICKNESS	5.266	mils	4.846		4.784		5.310		6.123	
	0.134	mm	0.123		0.122		0.135		0.156	
THICKNESS AVERAGE	5.456	mils								
	0.139	mm								
IVD WEIGHTS	2.3	mg	2.2	2.0	0.8	2.3	1.6	6.4	2.5	0.9
	TOTALS									
PISTON WEIGHTS	4.532	gm	1.3145		1.0791		0.9081		1.2306	
HEAD WEIGHTS	4.004	gm	1.1202		1.0543		0.8021		1.0277	
TOTAL CCD WEIGHTS	8.537	gm								
RATINGS										
INTAKE RUNNER	9.769	merit	9.795		9.755		9.745		9.780	
VALVE TULIP	9.450	merit	9.400		9.600		9.550		9.250	
INTAKE PORT	9.751	merit	9.760	9.74	9.780	9.695	9.760	9.75	9.740	9.78
PISTON TOP	7.964	merit	7.865		8.126		8.062		7.803	
CHAMBER	7.705	merit	7.622		7.766		7.692		7.740	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MMASOAK	DC2-12-0012A	6	C	RF-A	Robert	07.28.2001	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	6.175	mils	7.512		7.167		3.854		6.168	
	0.157	mm	0.191		0.182		0.098		0.157	
HEAD THICKNESS	4.303	mils	4.077		4.502		4.830		3.802	
	0.109	mm	0.104		0.114		0.123		0.097	
THICKNESS AVERAGE	5.239	mils								
	0.133	mm								
IVD WEIGHTS	168.5	mg	220.9	156.9	127.9	130.3	178.3	97.6	226.2	210.2
	TOTALS									
PISTON WEIGHTS	5.303	gm	1.5197		1.5574		0.9027		1.3235	
HEAD WEIGHTS	3.385	gm	1.0640		0.8998		0.6940		0.7275	
TOTAL CCD WEIGHTS	8.689	gm								
RATINGS										
INTAKE RUNNER	9.743	merit	9.608		9.853		9.670		9.840	
VALVE TULIP	8.213	merit	8.100		8.300		8.450		8.000	
INTAKE PORT	9.112	merit	9.368	8.902	9.197	9.074	9.138	9.106	8.803	9.306
PISTON TOP	7.598	merit	7.615		7.543		7.742		7.493	
CHAMBER	7.512	merit	7.484		7.533		7.480		7.552	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MMASOAK	DC2-13-0013	5	E	RF-A	Robert	08.12.2001	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	4.489	mils	5.825		4.819		3.130		4.180	
	0.114	mm	0.148		0.122		0.080		0.106	
HEAD THICKNESS	5.747	mils	5.160		5.547		5.389		6.892	
	0.146	mm	0.131		0.141		0.137		0.175	
THICKNESS AVERAGE	5.118	mils								
	0.130	mm								
IVD WEIGHTS	404.1	mg	410.4	448.1	444.1	424.5	384.7	380.0	381.8	359.5
	TOTALS									
PISTON WEIGHTS	3.631	gm	1.1192		0.9690		0.6384		0.9042	
HEAD WEIGHTS	3.108	gm	0.9226		0.8150		0.6260		0.7445	
TOTAL CCD WEIGHTS	6.739	gm								
RATINGS										
INTAKE RUNNER	9.472	merit	9.300		9.481		9.521		9.584	
VALVE TULIP	6.850	merit	6.900		6.850		6.950		6.700	
INTAKE PORT	8.106	merit	8.185	8.118	8.300	8.384	7.862	8.12	7.946	7.935
PISTON TOP	7.758	merit	7.707		7.701		7.802		7.822	
CHAMBER	7.898	merit	7.852		7.838		7.899		8.002	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MMASOAK	DC2-14-0014	6	A	RF-A	Robert	08.29.2001	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	6.155	mils	5.048		7.026		4.990		7.557	
	0.156	mm	0.128		0.178		0.127		0.192	
HEAD THICKNESS	5.723	mils	6.065		5.797		4.568		6.461	
	0.145	mm	0.154		0.147		0.116		0.164	
THICKNESS AVERAGE	5.939	mils								
	0.151	mm								
IVD WEIGHTS	9.5	mg	1.4	3.1	0.8	1.1	2.2	32.0	1.7	34.0
	TOTALS									
PISTON WEIGHTS	5.089	gm	1.2309		1.4306		1.0900		1.3374	
HEAD WEIGHTS	3.030	gm	0.7965		0.8457		0.6562		0.7311	
TOTAL CCD WEIGHTS	8.118	gm								
RATINGS										
INTAKE RUNNER	9.726	merit	9.726		9.742		9.728		9.707	
VALVE TULIP	9.638	merit	9.700		9.850		9.550		9.450	
INTAKE PORT	9.677	merit	9.686	9.74	9.643	9.714	9.665	9.708	9.563	9.697
PISTON TOP	8.020	merit	7.964		8.028		7.980		8.108	
CHAMBER	7.961	merit	7.935		8.001		7.884		8.024	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MMASOAK	DC2-15-0015	5	C	RF-A	Robert	09.18.2001	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	5.202	mils	4.407		6.517		4.322		5.563	
	0.132	mm	0.112		0.166		0.110		0.141	
HEAD THICKNESS	5.808	mils	5.467		6.712		5.246		5.808	
	0.148	mm	0.139		0.170		0.133		0.148	
THICKNESS AVERAGE	5.505	mils								
	0.140	mm								
IVD WEIGHTS	131.6	mg	107.3	30.3	238.5	90.8	171.3	94.8	154.5	165.2
	TOTALS									
PISTON WEIGHTS	4.675	gm	1.1212		1.3035		1.0178		1.2322	
HEAD WEIGHTS	3.416	gm	0.8309		0.9202		0.7529		0.9122	
TOTAL CCD WEIGHTS	8.091	gm								
RATINGS										
INTAKE RUNNER	9.609	merit	9.511		9.745		9.530		9.648	
VALVE TULIP	8.263	merit	8.550		7.800		8.400		8.300	
INTAKE PORT	9.360	merit	9.481	9.238	9.526	9.449	9.232	9.384	9.249	9.32
PISTON TOP	8.318	merit	7.801		7.908		9.704		7.857	
CHAMBER	7.518	merit	7.567		7.420		7.552		7.531	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MMASOAK	DC2-16-0016	6	E	RF-A	Robert	10.04.2001	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	6.315	mils	6.916		7.315		4.494		6.536	
	0.160	mm	0.176		0.186		0.114		0.166	
HEAD THICKNESS	6.076	mils	5.354		6.633		5.521		6.794	
	0.154	mm	0.136		0.168		0.140		0.173	
THICKNESS AVERAGE	6.195	mils								
	0.157	mm								
IVD WEIGHTS	528.2	mg	513.5	482.0	523.2	498.8	497.4	435.5	599.3	676.0
	TOTALS									
PISTON WEIGHTS	5.407	gm	1.4659		1.6253		0.9368		1.3788	
HEAD WEIGHTS	3.167	gm	0.7873		0.8404		0.7213		0.8180	
TOTAL CCD WEIGHTS	8.574	gm								
RATINGS										
INTAKE RUNNER	9.404	merit	9.458		9.200		9.418		9.538	
VALVE TULIP	6.388	merit	6.550		6.450		6.450		6.100	
INTAKE PORT	8.672	merit	8.704	8.656	8.646	8.636	8.631	8.696	8.623	8.783
PISTON TOP	8.198	merit	8.253		8.128		8.178		8.232	
CHAMBER	8.034	merit	7.892		8.084		8.098		8.062	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MILDER	DC2-17-0017	5	D	RF-A	ORLANDO	01.18.2002	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	7.039	mils	7.193		7.860		7.089		6.015	
	0.179	mm	0.183		0.200		0.180		0.153	
HEAD THICKNESS	8.072	mils	7.811		7.222		8.730		8.524	
	0.205	mm	0.198		0.183		0.222		0.217	
THICKNESS AVERAGE	7.556	mils								
	0.192	mm								
IVD WEIGHTS	3.9	mg	3.2	2.7	6.6	7.6	2.5	0.8	5.5	2.5
	TOTALS									
PISTON WEIGHTS	5.538	gm	1.3251		1.5756		1.4734		1.1638	
HEAD WEIGHTS	5.036	gm	1.2647		1.2450		1.2930		1.2333	
TOTAL CCD WEIGHTS	10.574	gm								
RATINGS										
INTAKE RUNNER	9.595	merit	9.590		9.560		9.620		9.610	
VALVE TULIP	9.250	merit	9.150		9.250		8.900		9.700	
INTAKE PORT	9.583	merit	9.555	9.59	9.570	9.59	9.570	9.58	9.600	9.61
PISTON TOP	7.133	merit	7.135		7.115		7.183		7.100	
CHAMBER	7.152	merit	6.991		7.113		7.211		7.292	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MILDER	DC2-18-0018	6	E	RF-A	ORLANDO	02.05.2002	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	4.941	mils	5.057		5.708		4.940		4.059	
	0.126	mm	0.128		0.145		0.125		0.103	
HEAD THICKNESS	8.624	mils	9.094		7.803		8.332		9.265	
	0.219	mm	0.231		0.198		0.212		0.235	
THICKNESS AVERAGE	6.782	mils								
	0.172	mm								
IVD WEIGHTS	701.6	mg	851.0	609.8	515.1	619.2	698.6	675.4	921.1	722.7
	TOTALS									
PISTON WEIGHTS	4.363	gm	1.1713		1.1508		1.0998		0.9412	
HEAD WEIGHTS	4.379	gm	1.0973		1.0697		1.1124		1.0994	
TOTAL CCD WEIGHTS	8.742	gm								
RATINGS										
INTAKE RUNNER	8.621	merit	8.904		8.840		8.816		7.925	
VALVE TULIP	6.650	merit	6.550		6.750		6.650		6.650	
INTAKE PORT	7.725	merit	7.618	7.725	7.797	7.695	7.644	7.802	7.776	7.739
PISTON TOP	8.082	merit	8.033		7.975		8.045		8.273	
CHAMBER	7.641	merit	7.741		7.589		7.738		7.495	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MILDER	DC2-19-0019	5	E	RF-A	ORLANDO	02.26.2002	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	5.142	mils	5.650		5.954		4.277		4.686	
	0.131	mm	0.144		0.151		0.109		0.119	
HEAD THICKNESS	7.871	mils	8.185		8.366		8.398		6.533	
	0.200	mm	0.208		0.212		0.213		0.166	
THICKNESS AVERAGE	6.506	mils								
	0.165	mm								
IVD WEIGHTS	749.3	mg	956.0	411.0	499.0	785.4	637.3	816.8	878.4	1010.1
	TOTALS									
PISTON WEIGHTS	3.813	gm	1.0087		1.0444		0.8789		0.8810	
HEAD WEIGHTS	4.708	gm	1.2410		1.3414		1.1201		1.0051	
TOTAL CCD WEIGHTS	8.521	gm								
RATINGS										
INTAKE RUNNER	8.553	merit	8.565		8.550		8.495		8.600	
VALVE TULIP	6.913	merit	6.900		7.100		6.800		6.850	
INTAKE PORT	6.981	merit	6.980	6.93	7.010	7.08	6.924	7	6.930	6.996
PISTON TOP	7.645	merit	7.565		7.485		7.743		7.786	
CHAMBER	7.098	merit	6.754		6.718		7.322		7.597	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MILDER	DC2-20-0020	6	D	RF-A	ORLANDO	03.18.2002	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	6.899	mils	6.641		7.577		6.633		6.746	
	0.175	mm	0.169		0.192		0.168		0.171	
HEAD THICKNESS	8.829	mils	8.855		9.098		9.041		8.320	
	0.224	mm	0.225		0.231		0.230		0.211	
THICKNESS AVERAGE	7.864	mils								
	0.200	mm								
IVD WEIGHTS	1.8	mg	3.0	2.6	0.2	1.6	0.8	2.4	1.2	2.8
	TOTALS									
PISTON WEIGHTS	5.478	gm	1.3528		1.4914		1.2893		1.3443	
HEAD WEIGHTS	5.166	gm	1.3334		1.4540		1.1864		1.1917	
TOTAL CCD WEIGHTS	10.643	gm								
RATINGS										
INTAKE RUNNER	9.550	merit	9.415		9.640		9.560		9.585	
VALVE TULIP	9.588	merit	9.650		9.400		9.650		9.650	
INTAKE PORT	9.474	merit	9.510	9.51	9.480	9.48	9.440	9.46	9.450	9.46
PISTON TOP	6.999	merit	6.871		7.103		7.110		6.910	
CHAMBER	6.701	merit	6.698		6.830		6.622		6.653	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MLD-1	DC2-21-0021A	7	E	RF-A	ORLANDO	07.10.2002	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	3.539	mils	3.484		3.771		3.750		3.150	
	0.090	mm	0.088		0.096		0.095		0.080	
HEAD THICKNESS	5.581	mils	6.995		6.104		3.634		5.591	
	0.142	mm	0.178		0.155		0.092		0.142	
THICKNESS AVERAGE	4.560	mils								
	0.116	mm								
IVD WEIGHTS	621.4	mg	516.4	696.4	668.1	651.4	566.8	675.4	655.5	540.8
	TOTALS									
PISTON WEIGHTS	3.105	gm	0.7590		0.8479		0.8085		0.6897	
HEAD WEIGHTS	3.141	gm	0.8106		0.8678		0.7466		0.7164	
TOTAL CCD WEIGHTS	6.247	gm								
RATINGS										
INTAKE RUNNER	9.077	merit	9.045		9.043		9.025		9.195	
VALVE TULIP	6.700	merit	6.850		6.750		6.750		6.450	
INTAKE PORT	7.793	merit	7.910	7.825	7.992	7.81	7.760	7.78	7.475	7.79
PISTON TOP	7.782	merit	7.838		7.690		7.782		7.816	
CHAMBER	7.966	merit	7.916		7.926		8.040		7.980	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MLD-1	DC2-22-0022	8	D	RF-A	ORLANDO	07.25.2002	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	5.170	mils	4.729		5.501		5.391		5.058	
	0.131	mm	0.120		0.140		0.137		0.128	
HEAD THICKNESS	6.193	mils	6.442		7.640		5.190		5.499	
	0.157	mm	0.164		0.194		0.132		0.140	
THICKNESS AVERAGE	5.681	mils								
	0.144	mm								
IVD WEIGHTS	3.8	mg	3.3	4.3	4.0	1.7	5.7	8.5	0.8	2.3
	TOTALS									
PISTON WEIGHTS	4.461	gm	1.0148		1.1904		1.2017		1.0537	
HEAD WEIGHTS	4.184	gm	1.0537		1.0432		1.0990		0.9877	
TOTAL CCD WEIGHTS	8.644	gm								
RATINGS										
INTAKE RUNNER	9.846	merit	9.866		9.878		9.767		9.872	
VALVE TULIP	9.200	merit	9.250		9.100		9.100		9.350	
INTAKE PORT	9.698	merit	9.725	9.758	9.711	9.655	9.670	9.691	9.658	9.715
PISTON TOP	7.567	merit	7.596		7.540		7.573		7.557	
CHAMBER	7.668	merit	7.642		7.608		7.669		7.752	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MLD-10	DC2-23-0023	7	D	RF-A	ROBERT	08.13.2002	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	5.525	mils	5.546		5.452		5.072		6.029	
	0.140	mm	0.141		0.138		0.129		0.153	
HEAD THICKNESS	6.809	mils	5.182		6.960		7.680		7.415	
	0.173	mm	0.132		0.177		0.195		0.188	
THICKNESS AVERAGE	6.167	mils								
	0.157	mm								
IVD WEIGHTS	2.4	mg	4.7	4.1	2.4	.0.5	1.1	1.6	0.3	2.3
	TOTALS									
PISTON WEIGHTS	5.032	gm	1.2060		1.2655		1.1646		1.3959	
HEAD WEIGHTS	4.183	gm	1.1864		0.9736		0.9827		1.0400	
TOTAL CCD WEIGHTS	9.215	gm								
RATINGS										
INTAKE RUNNER	9.807	merit	9.812		9.807		9.793		9.814	
VALVE TULIP	9.513	merit	9.250		9.500		9.650		9.650	
INTAKE PORT	9.743	merit	9.750	9.708	9.754	9.738	9.784	9.79	9.842	9.58
PISTON TOP	8.232	merit	8.113		8.244		8.266		8.305	
CHAMBER	8.172	merit	8.189		8.089		8.251		8.158	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			SIM-15	DC2-24-0024	8	D	RF-A	ORLANDO	09.04.2002	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	7.001	mils	7.424		7.154		6.684		6.742	
	0.178	mm	0.189		0.182		0.170		0.171	
HEAD THICKNESS	7.939	mils	9.042		8.235		7.793		6.685	
	0.202	mm	0.230		0.209		0.198		0.170	
THICKNESS AVERAGE	7.470	mils								
	0.190	mm								
IVD WEIGHTS	1.7	mg	2.1	1.9	0.5	0.3	2.3	1.9	1.8	3.0
	TOTALS									
PISTON WEIGHTS	5.194	gm	1.2526		1.3927		1.3012		1.2476	
HEAD WEIGHTS	4.836	gm	1.1862		1.1709		1.3380		1.1406	
TOTAL CCD WEIGHTS	10.030	gm								
RATINGS										
INTAKE RUNNER	9.553	merit	9.340		9.610		9.645		9.615	
VALVE TULIP	9.550	merit	9.500		9.500		9.450		9.750	
INTAKE PORT	9.500	merit	9.362	9.348	9.470	9.632	9.504	9.677	9.549	9.456
PISTON TOP	7.124	merit	7.100		7.090		7.160		7.145	
CHAMBER	7.238	merit	7.212		7.215		7.281		7.242	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			SIM-15	DC2-25-0025	7	E	RF-A	ORLANDO	09.28.2002	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	4.069	mils	4.354		4.207		3.999		3.714	
	0.103	mm	0.111		0.107		0.102		0.094	
HEAD THICKNESS	6.766	mils	7.270		8.140		7.090		4.562	
	0.172	mm	0.185		0.207		0.180		0.116	
THICKNESS AVERAGE	5.417	mils								
	0.138	mm								
IVD WEIGHTS	725.1	mg	742.7	717.4	692.0	778.8	772.5	649.1	616.4	831.7
	TOTALS									
PISTON WEIGHTS	3.307	gm	0.8717		0.9100		0.7941		0.7316	
HEAD WEIGHTS	4.155	gm	1.0540		1.1120		1.0310		0.9580	
TOTAL CCD WEIGHTS	7.462	gm								
RATINGS										
INTAKE RUNNER	9.115	merit	8.975		9.030		9.155		9.300	
VALVE TULIP	6.825	merit	6.800		6.950		6.900		6.650	
INTAKE PORT	7.899	merit	7.930	7.897	7.856	7.936	7.848	7.975	7.929	7.822
PISTON TOP	7.563	merit	7.640		7.271		7.618		7.722	
CHAMBER	7.772	merit	7.738		7.770		7.747		7.834	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MLD-10	DC2-26-0026	8	E	RF-A	ORLANDO	4/17/2003	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	3.760	mils	3.844		3.844		3.995		3.358	
	0.096	mm	0.098		0.098		0.101		0.085	
HEAD THICKNESS	6.555	mils	5.657		7.700		6.646		6.215	
	0.166	mm	0.144		0.196		0.169		0.158	
THICKNESS AVERAGE	5.157	mils								
	0.131	mm								
IVD WEIGHTS	777.1	mg	851.2	806.0	594.4	702.6	738.9	829.9	776.4	917.2
	TOTALS									
PISTON WEIGHTS	4.150	gm	0.8498		1.5055		0.9721		0.8221	
HEAD WEIGHTS	3.414	gm	0.8170		0.8930		0.9100		0.7940	
TOTAL CCD WEIGHTS	7.564	gm								
RATINGS										
INTAKE RUNNER	9.182	merit	9.077		9.186		9.136		9.328	
VALVE TULIP	6.725	merit	6.650		6.850		6.650		6.750	
INTAKE PORT	8.190	merit	8.218	8.142	8.044	8.144	8.081	8.401	8.218	8.274
PISTON TOP	7.565	merit	7.680		7.378		7.470		7.730	
CHAMBER	7.262	merit	7.386		7.173		7.202		7.288	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MLD-10	DC2-27-0027	7	E	RF-A	ROBERT	5/13/2003	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	3.895	mils	3.272		5.410		4.228		2.670	
	0.099	mm	0.083		0.137		0.107		0.068	
HEAD THICKNESS	7.240	mils	6.876		8.402		6.728		6.954	
	0.184	mm	0.175		0.213		0.171		0.177	
THICKNESS AVERAGE	5.568	mils								
	0.141	mm								
IVD WEIGHTS	714.3	mg	701.1	836.4	703.9	680.6	754.0	606.6	733.9	698.2
	TOTALS									
PISTON WEIGHTS	3.765	gm	0.7798		1.3019		0.8738		0.8091	
HEAD WEIGHTS	3.871	gm	0.8855		1.0974		0.9630		0.9252	
TOTAL CCD WEIGHTS	7.636	gm								
RATINGS										
INTAKE RUNNER	9.484	merit	9.430		9.490		9.430		9.585	
VALVE TULIP	6.388	merit	6.500		6.200		6.500		6.350	
INTAKE PORT	7.812	merit	7.952	8.02	7.415	7.915	7.850	7.96	7.647	7.74
PISTON TOP	7.428	merit	7.510		7.299		7.400		7.502	
CHAMBER	7.424	merit	7.429		7.372		7.372		7.524	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MLD-10	DC2-28-0028	8	D	RF-A	GARCIA	5/19/2003	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	15.138	mils	31.078		5.757		4.473		19.243	
	0.384	mm	0.789		0.146		0.114		0.489	
HEAD THICKNESS	6.962	mils	5.379		9.579		6.627		6.263	
	0.177	mm	0.137		0.243		0.168		0.159	
THICKNESS AVERAGE	11.050	mils								
	0.281	mm								
IVD WEIGHTS	8.0	mg	6.8	19.5	3.3	15.7	1.5	5.1	1.0	10.9
	TOTALS									
PISTON WEIGHTS	4.593	gm	0.9544		1.4440		1.1080		1.0863	
HEAD WEIGHTS	3.606	gm	0.8159		1.0421		0.8346		0.9135	
TOTAL CCD WEIGHTS	8.199	gm								
RATINGS										
INTAKE RUNNER	9.628	merit	9.610		9.660		9.585		9.655	
VALVE TULIP	9.525	merit	9.350		9.550		9.600		9.600	
INTAKE PORT	9.648	merit	9.750	9.63	9.570	9.7	9.635	9.69	9.610	9.6
PISTON TOP	7.120	merit	7.383		6.883		7.115		7.100	
CHAMBER	7.109	merit	7.178		6.921		7.110		7.228	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MLD-10	DC2-29-0029A	7	D	RF-A	GARCIA	6/19/2003	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	5.059	mils	5.132		5.585		5.250		4.270	
	0.129	mm	0.130		0.142		0.133		0.108	
HEAD THICKNESS	7.324	mils	7.709		7.495		7.058		7.034	
	0.186	mm	0.196		0.190		0.179		0.179	
THICKNESS AVERAGE	6.192	mils								
	0.157	mm								
IVD WEIGHTS	11.2	mg	4.8	2.1	71.4	2.6	1.2	3.1	2.3	1.9
	TOTALS									
PISTON WEIGHTS	4.692	gm	1.2214		1.3665		1.0703		1.0337	
HEAD WEIGHTS	4.343	gm	1.1221		1.0639		1.0696		1.0877	
TOTAL CCD WEIGHTS	9.035	gm								
RATINGS										
INTAKE RUNNER	9.690	merit	9.620		9.725		9.655		9.760	
VALVE TULIP	9.588	merit	9.650		9.150		9.750		9.800	
INTAKE PORT	9.685	merit	9.593	9.711	9.740	9.561	9.728	9.699	9.742	9.704
PISTON TOP	7.183	merit	7.205		7.173		7.179		7.174	
CHAMBER	7.088	merit	7.142		7.044		7.110		7.055	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MLD-10	DC2-30-0030	8	A	RF-A	GARCIA	7/9/2003	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	6.378	mils	6.769		6.399		6.114		6.231	
	0.162	mm	0.172		0.163		0.155		0.158	
HEAD THICKNESS	6.630	mils	5.648		5.703		7.125		8.044	
	0.168	mm	0.143		0.145		0.181		0.204	
THICKNESS AVERAGE	6.504	mils								
	0.165	mm								
IVD WEIGHTS	202.1	mg	455.2	280.6	209.1	181.9	64.6	232.6	179.0	13.4
	TOTALS									
PISTON WEIGHTS	4.186	gm	1.0929		1.0601		0.9649		1.0683	
HEAD WEIGHTS	3.451	gm	0.8843		0.8415		0.8197		0.9050	
TOTAL CCD WEIGHTS	7.637	gm								
RATINGS										
INTAKE RUNNER	9.416	merit	9.390		9.405		9.360		9.510	
VALVE TULIP	9.513	merit	9.350		9.550		9.550		9.600	
INTAKE PORT	9.086	merit	8.994	9.15	9.007	9.101	9.144	9.162	9.041	9.086
PISTON TOP	7.158	merit	7.145		7.200		7.180		7.106	
CHAMBER	7.297	merit	7.400		7.263		7.281		7.243	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MLD-10	DC2-31-0031	7	B	RF-A	GARCIA	07.23.03	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	4.531	mils	4.752		4.674		4.661		4.038	
	0.115	mm	0.121		0.119		0.118		0.103	
HEAD THICKNESS	6.136	mils	6.221		5.740		6.125		6.459	
	0.156	mm	0.158		0.146		0.156		0.164	
THICKNESS AVERAGE	5.334	mils								
	0.135	mm								
IVD WEIGHTS	353.8	mg	617.9	147.8	43.7	61.7	131.8	603.3	772.0	451.8
	TOTALS									
PISTON WEIGHTS	4.347	gm	1.0990		1.1238		1.1120		1.0124	
HEAD WEIGHTS	3.023	gm	0.7369		0.7444		0.7831		0.7584	
TOTAL CCD WEIGHTS	7.370	gm								
RATINGS										
INTAKE RUNNER	9.709	merit	9.825		9.710		9.670		9.630	
VALVE TULIP	9.703	merit	9.700		9.800		9.600		9.710	
INTAKE PORT	9.632	merit	9.585	9.63	9.615	9.675	9.630	9.63	9.600	9.69
PISTON TOP	7.590	merit	7.716		7.540		7.460		7.645	
CHAMBER	7.479	merit	7.521		7.460		7.469		7.467	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MLD-10	DC2-32-0032	8	C	RF-A	GARCIA	08.07.03	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	6.503	mils	7.404		6.337		6.080		6.190	
	0.165	mm	0.188		0.161		0.154		0.157	
HEAD THICKNESS	7.973	mils	6.847		7.690		7.868		9.487	
	0.203	mm	0.174		0.195		0.200		0.241	
THICKNESS AVERAGE	7.238	mils								
	0.184	mm								
IVD WEIGHTS	251.9	mg	781.7	58.2	44.1	54.3	292.7	240.5	109.8	433.9
	TOTALS									
PISTON WEIGHTS	3.978	gm	1.0743		0.9962		0.9304		0.9775	
HEAD WEIGHTS	3.979	gm	1.0097		1.0069		0.9305		1.0314	
TOTAL CCD WEIGHTS	7.957	gm								
RATINGS										
INTAKE RUNNER	9.654	merit	9.590		9.655		9.625		9.745	
VALVE TULIP	7.838	merit	7.850		8.150		7.550		7.800	
INTAKE PORT	8.757	merit	8.462	8.831	8.627	8.814	8.731	9.037	8.742	8.811
PISTON TOP	7.699	merit	7.682		7.752		7.560		7.802	
CHAMBER	7.269	merit	7.373		7.254		7.174		7.275	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			SIMPLE	DC3-01-0001	1	E	RF-A	ORLANDO	08.18.2000	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	3.741	mils	3.799		3.621		3.834		3.711	
	0.095	mm	0.096		0.092		0.097		0.094	
HEAD THICKNESS	4.454	mils	4.671		3.271		3.646		6.227	
	0.113	mm	0.119		0.083		0.093		0.158	
THICKNESS AVERAGE	4.098	mils								
	0.104	mm								
IVD WEIGHTS	520.5	mg	621.0	586.3	599.6	512.9	405.6	402.1	520.7	516.0
	TOTALS									
PISTON WEIGHTS	2.684	gm	0.6943		0.6759		0.6614		0.6521	
HEAD WEIGHTS	2.866	gm	0.7424		0.7590		0.6701		0.6947	
TOTAL CCD WEIGHTS	5.550	gm								
RATINGS										
INTAKE RUNNER	8.736	merit	8.465		8.850		8.855		8.775	
VALVE TULIP	6.975	merit	6.850		6.900		7.100		7.050	
INTAKE PORT	7.630	merit	7.829	7.38	7.484	7.414	7.597	7.719	7.796	7.824
PISTON TOP	7.422	merit	7.373		7.474		7.402		7.438	
CHAMBER	7.548	merit	7.526		7.572		7.606		7.488	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMA	DC3-02-0002	2	C	RF-A	ORLANDO	09.14.2000	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	5.268	mils	5.462		4.607		4.381		6.622	
	0.134	mm	0.139		0.117		0.111		0.168	
HEAD THICKNESS	5.505	mils	5.953		4.886		4.388		6.794	
	0.140	mm	0.151		0.124		0.111		0.173	
THICKNESS AVERAGE	5.387	mils								
	0.137	mm								
IVD WEIGHTS	497.3	mg	436.6	766.5	380.5	385.0	432.4	547.6	330.6	699.5
	TOTALS									
PISTON WEIGHTS	4.091	gm	1.0606		1.2297		0.8937		0.9069	
HEAD WEIGHTS	3.351	gm	0.7823		1.0445		0.7482		0.7761	
TOTAL CCD WEIGHTS	7.442	gm								
RATINGS										
INTAKE RUNNER	9.258	merit	9.236		9.267		9.200		9.328	
VALVE TULIP	7.000	merit	6.800		7.350		6.900		6.950	
INTAKE PORT	8.962	merit	8.886	8.8	9.112	9.012	9.026	9.024	8.810	9.022
PISTON TOP	7.855	merit	8.062		7.844		7.508		8.004	
CHAMBER	7.139	merit	7.065		7.216		7.102		7.173	

DC CCD DATA										
PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			SIMPLE	DC3-03-000	1	D	RF-A	ROBERT	10.02.2000	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	6.132	mils	6.079		6.170		5.841		6.438	
	0.156	mm	0.154		0.157		0.148		0.164	
HEAD THICKNESS	7.496	mils	8.014		8.154		6.403		7.413	
	0.190	mm	0.204		0.207		0.163		0.188	
THICKNESS AVERAGE	6.814	mils								
	0.173	mm								
IVD WEIGHTS	1.5	mg	4.5	0.3	0.3	2.8	1.3	1.2	1.1	0.2
	TOTALS									
PISTON WEIGHTS	4.838	gm	1.1810		1.2459		1.2175		1.1937	
HEAD WEIGHTS	4.233	gm	1.0804		1.1519		0.9736		1.0266	
TOTAL CCD WEIGHTS	9.071	gm								
RATINGS										
INTAKE RUNNER	9.815	merit	9.819		9.828		9.811		9.801	
VALVE TULIP	9.663	merit	9.500		9.600		9.800		9.750	
INTAKE PORT	9.807	merit	9.821	9.786	9.818	9.827	9.842	9.767	9.779	9.819
PISTON TOP	7.936	merit	7.961		7.931		7.860		7.992	
CHAMBER	7.657	merit	7.691		7.600		7.674		7.662	

DC CCD DATA										
PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMA	DC3-04-0004	2	A	RF-A	ROBERT	10.21.2000	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	6.310	mils	7.060		6.732		5.791		5.656	
	0.160	mm	0.179		0.171		0.147		0.144	
HEAD THICKNESS	5.972	mils	6.617		5.926		5.007		6.339	
	0.152	mm	0.168		0.151		0.127		0.161	
THICKNESS AVERAGE	6.141	mils								
	0.156	mm								
IVD WEIGHTS	4.4	mg	1.1	0.0	1.3	0.9	1.0	2.2	2.8	25.8
	TOTALS									
PISTON WEIGHTS	5.928	gm	1.4586		2.0897		1.1631		1.2161	
HEAD WEIGHTS	3.713	gm	1.0405		0.8966		0.8166		0.9597	
TOTAL CCD WEIGHTS	9.641	gm								
RATINGS										
INTAKE RUNNER	9.646	merit	9.727		9.630		9.484		9.742	
VALVE TULIP	9.588	merit	9.700		9.700		9.500		9.450	
INTAKE PORT	9.448	merit	9.451	9.528	9.370	9.596	9.625	9.307	9.316	9.388
PISTON TOP	7.433	merit	7.427		7.396		7.385		7.524	
CHAMBER	7.631	merit	7.788		7.677		7.581		7.479	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			SIMPLE	DC3-05-0005	1	C	RF-A	ROBERT	11.07.2000	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	5.341	mils	5.850		4.856		5.249		5.409	
	0.136	mm	0.149		0.123		0.133		0.137	
HEAD THICKNESS	6.198	mils	6.602		6.222		5.592		6.377	
	0.157	mm	0.168		0.158		0.142		0.162	
THICKNESS AVERAGE	5.770	mils								
	0.147	mm								
IVD WEIGHTS	4.8	mg	10.9	1.1	3.0	5.4	3.1	2.4	2.5	10.1
	TOTALS									
PISTON WEIGHTS	3.896	gm	0.9806		0.9553		0.9530		1.0075	
HEAD WEIGHTS	3.307	gm	0.7520		0.8895		0.8168		0.8491	
TOTAL CCD WEIGHTS	7.204	gm								
RATINGS										
INTAKE RUNNER	9.262	merit	9.150		9.218		9.365		9.313	
VALVE TULIP	9.288	merit	9.300		9.500		9.650		8.700	
INTAKE PORT	8.998	merit	9.083	8.966	8.930	9.097	9.074	8.849	9.029	8.953
PISTON TOP	7.631	merit	7.588		7.728		7.650		7.558	
CHAMBER	7.460	merit	7.475		7.515		7.420		7.430	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMA	DC3-06-0006A	2	E	RF-A	ROBERT	01.23.2001	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	3.497	mils	3.549		3.688		3.326		3.424	
	0.089	mm	0.090		0.094		0.084		0.087	
HEAD THICKNESS	5.999	mils	6.588		6.850		4.368		6.188	
	0.152	mm	0.167		0.174		0.111		0.157	
THICKNESS AVERAGE	4.748	mils								
	0.121	mm								
IVD WEIGHTS	531.3	mg	446.1	692.5	473.2	466.3	443.0	567.8	623.1	538.4
	TOTALS									
PISTON WEIGHTS	2.899	gm	0.7863		0.6747		0.6584		0.7800	
HEAD WEIGHTS	2.937	gm	0.8325		0.7261		0.6305		0.7481	
TOTAL CCD WEIGHTS	5.837	gm								
RATINGS										
INTAKE RUNNER	8.080	merit	8.029		8.075		7.900		8.317	
VALVE TULIP	6.638	merit	6.700		6.600		6.600		6.650	
INTAKE PORT	7.908	merit	8.230	7.631	7.847	8.046	7.833	7.923	8.020	7.733
PISTON TOP	8.100	merit	8.185		8.122		8.031		8.061	
CHAMBER	7.530	merit	7.388		7.470		7.615		7.645	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			SIMPLE	DC3-07-0007	1	B	RF-A	ROBERT	02.12.2001	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	6.848	mils	8.216		6.526		6.740		5.910	
	0.174	mm	0.209		0.166		0.171		0.150	
HEAD THICKNESS	6.919	mils	6.565		7.327		8.472		5.310	
	0.176	mm	0.167		0.186		0.215		0.135	
THICKNESS AVERAGE	6.883	mils								
	0.175	mm								
IVD WEIGHTS	6.4	mg	2.3	2.6	32.6	6.1	3.1	1.1	0.5	2.6
	TOTALS									
PISTON WEIGHTS	5.046	gm	1.3291		1.2286		1.2855		1.2031	
HEAD WEIGHTS	3.140	gm	0.7762		0.7796		0.7487		0.8352	
TOTAL CCD WEIGHTS	8.186	gm								
RATINGS										
INTAKE RUNNER	9.770	merit	9.787		9.767		9.688		9.836	
VALVE TULIP	9.688	merit	9.850		9.450		9.850		9.600	
INTAKE PORT	9.715	merit	9.700	9.765	9.728	9.646	9.696	9.725	9.652	9.804
PISTON TOP	7.325	merit	7.345		7.415		7.263		7.278	
CHAMBER	7.784	merit	7.821		7.694		7.802		7.819	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMA	DC3-08-0008	2	B	RF-A	ROBERT	02.27.2001	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	4.683	mils	5.736		4.707		3.463		4.826	
	0.119	mm	0.146		0.120		0.088		0.123	
HEAD THICKNESS	4.406	mils	6.371		3.878		2.585		4.788	
	0.112	mm	0.162		0.099		0.066		0.122	
THICKNESS AVERAGE	4.544	mils								
	0.115	mm								
IVD WEIGHTS	11.4	mg	5.1	3.2	11.4	9.4	10.6	14.1	10.0	27.5
	TOTALS									
PISTON WEIGHTS	3.658	gm	1.1307		0.8319		0.7886		0.9066	
HEAD WEIGHTS	2.503	gm	0.7406		0.5491		0.5728		0.6402	
TOTAL CCD WEIGHTS	6.161	gm								
RATINGS										
INTAKE RUNNER	9.616	merit	9.593		9.548		9.574		9.748	
VALVE TULIP	9.088	merit	9.400		9.250		8.900		8.800	
INTAKE PORT	9.659	merit	9.692	9.67	9.637	9.7	9.626	9.59	9.638	9.715
PISTON TOP	7.676	merit	7.628		7.635		7.661		7.778	
CHAMBER	7.722	merit	7.879		7.694		7.614		7.701	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			SIMPLE	DC3-09-0009	1	ADDITIVE	RF-A	ROBERT	03.14.2001	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	6.280	mils	6.131		6.020		6.883		6.087	
	0.160	mm	0.156		0.153		0.175		0.155	
HEAD THICKNESS	6.630	mils	6.850		6.283		6.244		7.141	
	0.168	mm	0.174		0.160		0.159		0.181	
THICKNESS AVERAGE	6.455	mils								
	0.164	mm								
IVD WEIGHTS	1.0	mg	0.7	0.8	0.0	0.8	1.4	1.2	0.1	2.7
	TOTALS									
PISTON WEIGHTS	4.970	gm	1.1695		1.2151		1.2982		1.2869	
HEAD WEIGHTS	4.042	gm	1.0965		1.0084		0.9538		0.9831	
TOTAL CCD WEIGHTS	9.012	gm								
RATINGS										
INTAKE RUNNER	9.510	merit	9.499		9.431		9.474		9.634	
VALVE TULIP	9.675	merit	9.650		9.750		9.750		9.550	
INTAKE PORT	9.535	merit	9.570	9.553	9.528	9.504	9.518	9.535	9.543	9.526
PISTON TOP	7.783	merit	7.825		7.784		7.767		7.754	
CHAMBER	7.465	merit	7.456		7.444		7.500		7.458	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMA	DC3-10-0010	2	ADDITIVE	D	ROBERT	03.27.2001	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	6.368	mils	6.664		5.704		7.083		6.020	
	0.162	mm	0.169		0.145		0.180		0.153	
HEAD THICKNESS	6.968	mils	8.205		6.698		5.514		7.453	
	0.177	mm	0.208		0.170		0.140		0.189	
THICKNESS AVERAGE	6.668	mils								
	0.169	mm								
IVD WEIGHTS	3.4	mg	0.3	1.6	0.5	1.7	1.7	0.0	1.8	19.7
	TOTALS									
PISTON WEIGHTS	5.108	gm	1.2844		1.2267		1.2865		1.3102	
HEAD WEIGHTS	3.848	gm	1.0957		0.9494		0.8176		0.9853	
TOTAL CCD WEIGHTS	8.956	gm								
RATINGS										
INTAKE RUNNER	9.755	merit	9.730		9.775		9.740		9.774	
VALVE TULIP	9.600	merit	9.750		9.650		9.600		9.400	
INTAKE PORT	9.854	merit	9.796	9.868	9.864	9.874	9.862	9.852	9.856	9.858
PISTON TOP	7.317	merit	7.176		7.263		7.542		7.286	
CHAMBER	7.544	merit	7.469		7.540		7.614		7.553	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMA	DC3-11-0011A	3	ADDITIVE	A	ROBERT	08.12.2001	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	3.858	mils	4.226		3.693		3.385		4.129	
	0.098	mm	0.107		0.094		0.086		0.105	
HEAD THICKNESS	1.355	mils	1.221		1.289		1.442		1.467	
	0.034	mm	0.031		0.033		0.037		0.037	
THICKNESS AVERAGE	2.607	mils								
	0.066	mm								
IVD WEIGHTS	2.1	mg	3.4	2.8	2.3	2.3	0.6	1.4	1.6	2.1
	TOTALS									
PISTON WEIGHTS	2.698	gm	0.7521		0.6039		0.5661		0.7763	
HEAD WEIGHTS	1.526	gm	0.4040		0.3111		0.3137		0.4976	
TOTAL CCD WEIGHTS	4.225	gm								
RATINGS										
INTAKE RUNNER	9.603	merit	9.736		9.640		9.631		9.404	
VALVE TULIP	9.538	merit	9.400		9.550		9.650		9.550	
INTAKE PORT	9.587	merit	9.858	9.32	9.598	9.572	9.639	9.629	9.460	9.619
PISTON TOP	7.500	merit	7.380		7.478		7.562		7.578	
CHAMBER	7.866	merit	7.843		7.804		7.962		7.854	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMA	DC3-12-0012	4	ADDITIVE	E	ROBERT	08.28.2001	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	3.095	mils	3.554		3.458		2.831		2.536	
	0.079	mm	0.090		0.088		0.072		0.064	
HEAD THICKNESS	4.873	mils	4.660		5.397		5.121		4.313	
	0.124	mm	0.118		0.137		0.130		0.110	
THICKNESS AVERAGE	3.984	mils								
	0.101	mm								
IVD WEIGHTS	342.4	mg	301.0	322.4	302.5	392.3	397.5	282.8	357.4	383.0
	TOTALS									
PISTON WEIGHTS	2.675	gm	0.7556		0.6900		0.6674		0.5615	
HEAD WEIGHTS	2.605	gm	0.6785		0.6757		0.7018		0.5489	
TOTAL CCD WEIGHTS	5.279	gm								
RATINGS										
INTAKE RUNNER	9.167	merit	8.971		9.022		9.440		9.236	
VALVE TULIP	7.375	merit	7.350		7.450		7.450		7.250	
INTAKE PORT	8.517	merit	8.187	8.472	8.546	8.64	8.569	8.619	8.578	8.528
PISTON TOP	8.315	merit	8.322		8.299		8.336		8.301	
CHAMBER	8.229	merit	8.248		8.162		8.400		8.104	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMASK	DC3-13-0013	3	ADDITIVE	C	ROBERT	09.11.2001	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	4.478	mils	4.997		4.658		4.044		4.211	
	0.114	mm	0.127		0.118		0.103		0.107	
HEAD THICKNESS	5.378	mils	5.246		5.413		5.317		5.535	
	0.137	mm	0.133		0.137		0.135		0.141	
THICKNESS AVERAGE	4.928	mils								
	0.125	mm								
IVD WEIGHTS	25.3	mg	1.7	5.8	18.5	21.7	34.8	24.0	22.0	73.6
	TOTALS									
PISTON WEIGHTS	3.653	gm	0.9598		0.9538		0.7972		0.9417	
HEAD WEIGHTS	2.830	gm	0.6680		0.7671		0.6671		0.7279	
TOTAL CCD WEIGHTS	6.483	gm								
RATINGS										
INTAKE RUNNER	9.469	merit	9.510		9.449		9.458		9.460	
VALVE TULIP	9.138	merit	9.150		9.100		9.250		9.050	
INTAKE PORT	9.118	merit	9.125	9.084	8.954	9.199	9.050	9.251	8.973	9.311
PISTON TOP	7.278	merit	7.246		7.249		7.374		7.244	
CHAMBER	7.105	merit	7.051		7.131		7.077		7.159	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMASK	DC3-14-0014	4	ADDITIVE	D	ROBERT	10.03.2001	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	4.464	mils	4.934		4.072		3.875		4.976	
	0.113	mm	0.125		0.103		0.098		0.126	
HEAD THICKNESS	4.341	mils	4.858		3.456		3.960		5.091	
	0.110	mm	0.123		0.088		0.101		0.129	
THICKNESS AVERAGE	4.403	mils								
	0.112	mm								
IVD WEIGHTS	7.0	mg	3.3	5.6	4.8	9.1	5.9	9.8	10.2	7.2
	TOTALS									
PISTON WEIGHTS	3.088	gm	0.8787		0.6354		0.6739		0.8997	
HEAD WEIGHTS	2.671	gm	0.6702		0.6038		0.5796		0.8176	
TOTAL CCD WEIGHTS	5.759	gm								
RATINGS										
INTAKE RUNNER	9.668	merit	9.672		9.636		9.644		9.721	
VALVE TULIP	9.888	merit	9.900		9.850		9.950		9.850	
INTAKE PORT	9.786	merit	9.792	9.772	9.778	9.78	9.794	9.792	9.788	9.788
PISTON TOP	7.944	merit	7.876		7.981		7.979		7.938	
CHAMBER	7.925	merit	7.999		7.906		7.914		7.882	

DC CCD DATA

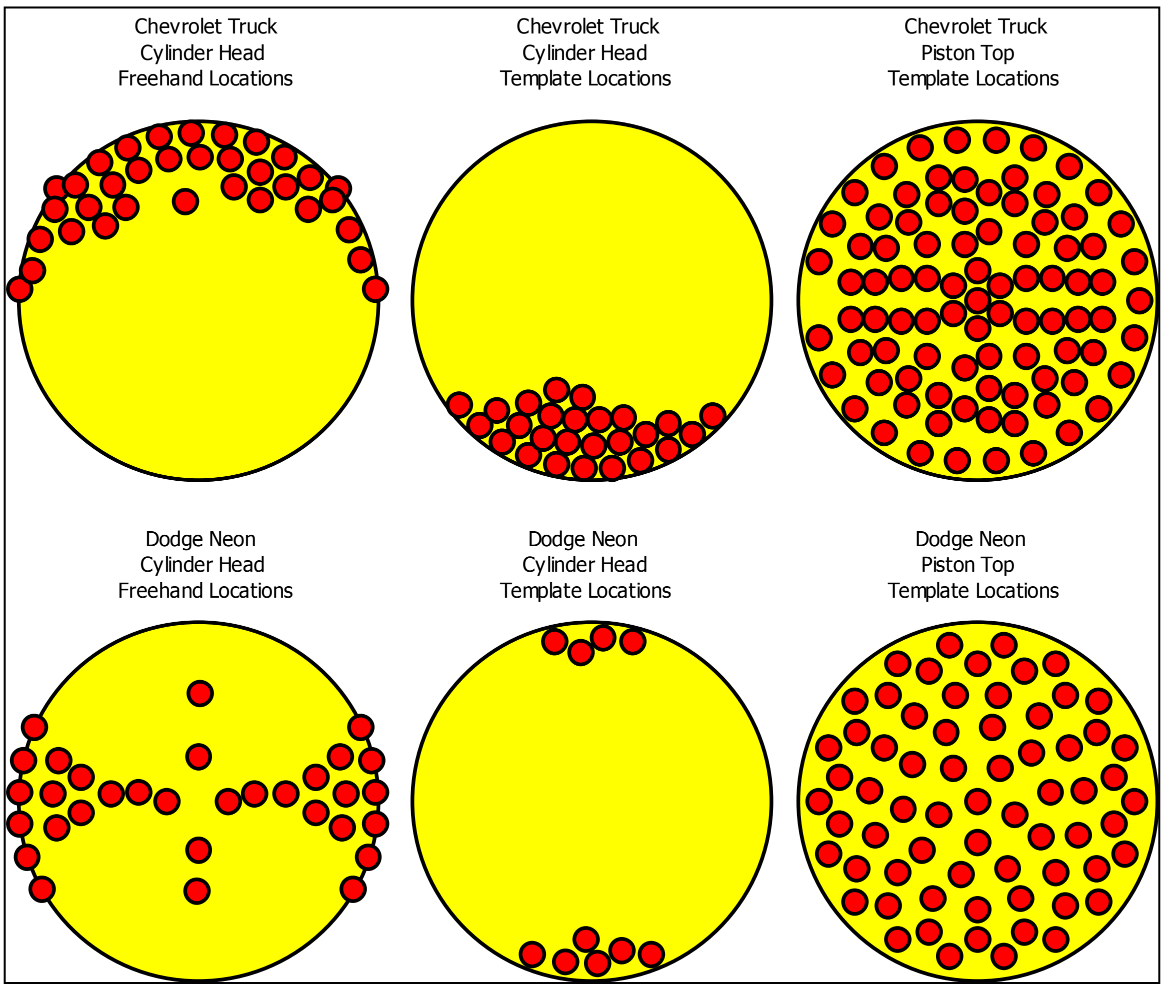
PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMASK	DC3-15-0015	3	D	RFA	ROBERT	10.26.2001	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	5.240	mils	5.421		5.673		4.438		5.428	
	0.133	mm	0.138		0.144		0.113		0.138	
HEAD THICKNESS	5.385	mils	5.477		4.974		5.224		5.865	
	0.137	mm	0.139		0.126		0.133		0.149	
THICKNESS AVERAGE	5.313	mils								
	0.135	mm								
IVD WEIGHTS	6.3	mg	5.8	6.7	6.6	6.8	6.4	6.4	3.7	7.7
	TOTALS									
PISTON WEIGHTS	3.931	gm	1.1206		0.9667		0.8228		1.0204	
HEAD WEIGHTS	3.494	gm	0.8543		0.8672		0.8219		0.9507	
TOTAL CCD WEIGHTS	7.425	gm								
RATINGS										
INTAKE RUNNER	9.817	merit	9.818		9.810		9.814		9.824	
VALVE TULIP	9.863	merit	9.850		9.850		9.900		9.850	
INTAKE PORT	9.806	merit	9.808	9.8	9.800	9.81	9.809	9.8	9.800	9.824
PISTON TOP	8.019	merit	8.020		7.966		8.097		7.993	
CHAMBER	7.916	merit	8.000		7.883		7.924		7.855	

DC CCD DATA

PARAMETER			CYCLE	TEST	HEADS	ADDITIVE	FUEL	RATER	DATE	
			MAMASK	DC3-16-0016	4	A	RFA	ROBERT	11.12.2001	
	AVERAGE	UNITS	1A	1B	2A	2B	3A	3B	4A	4B
PISTON THICKNESS	5.466	mils	5.462		5.081		5.750		5.571	
	0.139	mm	0.139		0.129		0.146		0.142	
HEAD THICKNESS	5.743	mils	6.108		5.178		5.821		5.863	
	0.146	mm	0.155		0.132		0.148		0.149	
THICKNESS AVERAGE	5.604	mils								
	0.142	mm								
IVD WEIGHTS	1.4	mg	0.2	1.3	0.9	2.9	2.7	1.0	0.5	1.6
	TOTALS									
PISTON WEIGHTS	4.234	gm	1.1751		1.0369		0.9480		1.0737	
HEAD WEIGHTS	4.048	gm	1.1458		1.0565		0.8790		0.9671	
TOTAL CCD WEIGHTS	8.282	gm								
RATINGS										
INTAKE RUNNER	9.656	merit	9.630		9.610		9.533		9.852	
VALVE TULIP	9.825	merit	9.800		9.800		9.850		9.850	
INTAKE PORT	9.614	merit	9.628	9.556	9.575	9.627	9.530	9.672	9.601	9.722
PISTON TOP	7.720	merit	7.688		7.628		7.655		7.907	
CHAMBER	7.725	merit	7.684		7.688		7.777		7.749	

APPENDIX D

CCD THICKNESS MEASUREMENT LOCATIONS



APPENDIX D

CERTIFICATE OF ANALYSIS OF RF-A BASE FUEL AMD INSPECTION DATA FROM PEAR

RF-A BASE FUEL

TESTS	RESULTS	SPECIFICATIONS	METHOD
Specific Gravity, 60/60 F	0.748	0.7479-0.7503	ASTM D 4052
Sulfur, ppm	333	330 +/- 30	ASTM D 2622
Reid Vapor Pressure, psi	8.75	8.4-8.9	ASTM D 323
Benzene Content, LV%	1.38	1.3-1.8	ASTM D 4815
DISTILLATION, F, % evaporated		Report	ASTM D 86
IBP	97.9		
5%	121.5		
10%	132.8	123-133	
20%	152.9		
30%	174.0		
40%	197.5		
50%	221.4	213-233	
60%	244.4		
70%	269.4		
80%	298.6		
90%	330.0	325-335	
95%	359.2		
EP	406.3		
Loss	0.8		
Residue	1.0		
HYDROCARBON TYPE, VOL. %			ASTM D 1319
Aromatics	31.2	32 +/- 2.7	
Olefins	8.8	9.2 +/- 2.5	
Saturates	60.0		
Research Octane Number	92.05	Report	ASTM D 2699
Motor Octane Number	83.15	Report	ASTM D 2700
Antiknock Index	87.6	87.3 +/- 0.5	

RF-A Inspection Data from PEAR

METHOD	TEST	DATE	08.01.2001	01.29.2002	09.18.2002	01.16.2003	04.28.2003	11.03.2003
ASTM D 4052	SPECIFIC GRAVITY 60/60 °F		0.7486	0.7480	0.7493	0.7505	0.7598	0.7515
			°F	°F	°F	°F	°F	°F
ASTM D 86	DISTILLATION	IBP	96.8	93.2	95	96.8	96.8	98.6
		5%	123.8	122	123.8	129.2	134.6	127.4
		10%	134.6	134.6	134.6	140	136.4	138.2
		20%	154.4	154.4	154.4	159.8	156.2	159.8
		30%	177.8	177.8	176	181.4	177.8	181.4
		40%	203	203	201.2	204.8	203	206.6
		50%	228.2	228.2	224.6	228.2	226.4	230
		60%	251.6	251.6	248	251.6	251.6	253.4
		70%	276.8	276.8	275	276.8	276.8	280.4
		80%	300.2	305.6	302	302	303.8	307.4
		90%	339.8	341.6	338	338	339.8	345.2
		95%	395.6	397.4	383	383	395.6	406.4
		FBP	404.6	404.6	402.8	411.8	402.8	415.4
		RECOVERED	95.7	95.7	96.3	96.3	95.9	95.7
		RESIDUE	1.1	1.1	1.2	1.1	1.1	1
		LOSS	2.5	2.6	2.0	2.4	2.4	2.7
D 381	GUM, UNWASHED	mg/100mL	3.6	10.2	7.0	13	4.4	3.6
D 381	GUM, WASHED	mg/100mL	2.2	6.8	3.0	1.0	1.6	1.4
			PEAR ORIGINAL FUEL BATCH			FUEL TOPPED OFF 11.2002		

APPENDIX E

DEPOSIT DATA TABULATIONS

OF THE ENGINE DYNAMOMETER PHASE

CHEVROLET SILIVERADO DYNOMOMETER DATA
(Page 1 of 2)

						CCD WEIGHTS			CCD RATINGS				
TEST NUMBER	CYCLE	FUEL	HEAD	BLOCK	EOT	PISTON	HEAD	TOTAL	RUNNER	TULIP	PORT	PISTON	CHAMBER
GM12-03-0003	MAMA	A	01,02	1	05.19.2000	9.005	8.980	17.985	9.634	9.713	8.676	7.005	7.442
GM13-08-0008	MAMA	A	03,04	1	09.13.2000	9.139	10.106	19.245	9.328	9.550	8.652	7.110	7.195
GM12-01-0001	MAMA	B	01,02	1	03.08.2000	10.320	8.135	18.456	9.702	9.313	9.259	7.237	7.578
GM13-02-0002A	MAMA	B	03,04	1	05.19.2000	10.011	7.166	17.177	9.707	9.425	9.255	7.084	7.433
GM12-09-0009	MAMA	C	01,02	1	09.09.2000	8.024	8.347	16.371	8.976	7.850	7.461	7.652	7.937
GM13-10-0010	MAMA	C	03,04	1	10.20.00	8.183	9.430	17.613	9.166	8.863	8.097	7.979	8.217
GM12-07-0007	MAMA	D	01,02	1	07.31.2000	12.042	9.408	21.450	9.715	9.588	9.546	6.960	7.380
GM13-06-0006	MAMA	D	03,04	1	08.01.2000	15.408	14.552	29.960	9.636	9.263	9.506	7.331	7.252
GM12-05-0005	MAMA	E	01,02	1	06.26.2000	6.732	9.670	16.403	8.904	7.475	7.122	7.543	7.528
GM13-04-0004	MAMA	E	03,04	1	06.26.2000	6.732	8.211	14.943	9.272	7.275	7.274	7.402	7.651
GM12-02-0006	SIMPLE	A	03,04	1	07.13.2000	7.400	8.501	15.901	9.046	9.5	9.136	7.718	8.172
GM13-01-0001	SIMPLE	A	01,02	1	03.03.2000	9.178	10.017	19.195	9.404	9.825	9.025	7.844	7.808
GM12-04-0004	SIMPLE	B	03,04	1	06.07.2000	8.962	7.835	16.797	9.666	9.575	9.399	7.467	7.655
GM13-09-0009	SIMPLE	B	01,02	1	10.04.00	9.288	7.794	17.082	9.614	9.750	9.474	7.329	7.747
GM12-08-0008	SIMPLE	C	03, 04	1	08.20.2000	8.562	8.208	16.770	8.578	7.738	7.362	7.841	7.712
GM13-07-0007	SIMPLE	C	01,02	1	08.21.2000	7.817	8.441	16.258	8.375	8.413	7.558	7.436	7.456
GM12-02-0002	SIMPLE	D	03,04	1	03.24.2000	12.377	10.330	22.707	9.682	9.900	9.311	7.152	7.485
GM13-05-0005	SIMPLE	D	01,02	1	07.16.2000	15.200	14.364	29.565	9.483	8.2	9.357	6.995	7.055
GM12-10-0010	SIMPLE	E	03,04	1	09.26.2000	8.719	10.046	18.766	8.635	7.688	7.109	8.047	8.009
GM13-03-0003	SIMPLE	E	01,02	1	06.05.2000	9.619	7.462	17.081	8.373	7.813	7.404	7.629	7.902

CHEVROLET SILVERADO DYNAMOMETER DATA
(Page 2 of 2)

						THICKNESS						IVD
						PISTON		HEAD		AVERAGE		WEIGHT
TEST NUMBER	CYCLE	FUEL	HEAD	BLOCK	EOT	MILS	MM	MILS	MM	MILS	MM	MG
GM12-03-0003	MAMA	A	01,02	1	05.19.2000	9.494	0.241	6.721	0.171	8.108	0.206	12.2
GM13-08-0008	MAMA	A	03,04	1	09.13.2000	5.121	0.130	6.128	0.156	5.624	0.143	6.6
GM12-01-0001	MAMA	B	01,02	1	03.08.2000	8.236	0.209	6.561	0.167	7.399	0.188	37.1
GM13-02-0002A	MAMA	B	03,04	1	05.19.2000	7.605	0.193	6.105	0.155	6.855	0.174	30.1
GM12-09-0009	MAMA	C	01,02	1	09.09.2000	3.971	0.101	6.643	0.169	5.307	0.135	355.4
GM13-10-0010	MAMA	C	03,04	1	10.20.00	4.150	0.105	5.051	0.128	4.601	0.117	43.3
GM12-07-0007	MAMA	D	01,02	1	07.31.2000	5.298	0.135	6.491	0.165	5.894	0.150	4.3
GM13-06-0006	MAMA	D	03,04	1	08.01.2000	8.231	0.209	8.629	0.219	8.430	0.214	17.7
GM12-05-0005	MAMA	E	01,02	1	06.26.2000	9.403	0.239	9.050	0.230	9.226	0.234	845.5
GM13-04-0004	MAMA	E	03,04	1	06.26.2000	10.819	0.275	7.913	0.201	9.366	0.238	867.2
GM12-02-0006	SIMPLE	A	03,04	1	07.13.2000	11.831	0.301	5.850	0.149	8.841	0.225	7.0
GM13-01-0001	SIMPLE	A	01,02	1	03.03.2000	4.148	0.105	4.694	0.119	4.421	0.112	10.9
GM12-04-0004	SIMPLE	B	03,04	1	06.07.2000	10.325	0.262	8.568	0.218	9.446	0.240	22.2
GM13-09-0009	SIMPLE	B	01,02	1	10.04.00	5.264	0.134	5.065	0.129	5.164	0.131	2.9
GM12-08-0008	SIMPLE	C	03, 04	1	08.20.2000	4.119	0.105	5.358	0.136	4.738	0.120	255.9

DODGE NEON DYNAMOMETER DATA

								CCD			CCD				
			GAL/	FUEL				WEIGHTS			RATINGS				
TEST NUMBER	CYCLE	FUEL	HOUR	DIL, %	HEAD	BLOCK	EOT	PISTON	HEAD	TOTAL	RUNNER	TULIP	PORT	PISTON	CHAMBER
DC2-07-0007	MAMA	A	2.17		2	2	11.08.00	4.1645	3.111	7.2753	9.71275	9.625	9.423	7.466	7.60225
DC3-04-0004	MAMA	A	2.17		2	1	10.21.00	5.9275	3.713	9.6409	9.64575	9.588	9.448	7.433	7.63125
DC2-05-0005	MAMA	B	2.17		2	2	10.09.00	3.3327	2.988	6.3209	9.67	9.463	9.771	7.4005	7.507
DC3-08-0008	MAMA	B	2.17		2	1	02.27.2001	3.658	2.503	6.161	9.616	9.088	9.659	7.676	7.722
DC2-03-0003	MAMA	C	2.17		1	2	07.18.2000	3.709	3.168	6.8766	9.0975	6.9	8.765	8.11225	7.352
DC3-02-0002	MAMA	C	2.17		2	1	9.14.2000	4.0909	3.351	7.442	9.25775	7	8.962	7.8545	7.139
DC2-01-0001A	MAMA	D	2.17		3	2	02.21.2001	4.685	3.764	8.45	9.774	9.263	9.65	7.45	7.374
DC3-10-0010	MAMA	D	2.17		2	1	03.27.2001	5.108	3.848	8.956	9.755	9.6	9.854	7.317	7.544
DC2-09-0009	MAMA	E	2.17		2	2	01.15.01	2.3767	3.425	5.8016	8.721	5.863	7.901	8.40325	7.8065
DC3-06-0006A	MAMA	E	2.17		2	1	01.24.01	2.8994	2.937	5.8366	8.08025	6.638	7.908	8.09975	7.5295
DC2-02-0002A	SIMPLE	A	1.67		2	2	03.08.2001	5.46	4.832	10.291	9.466	9.838	9.542	7.079	7.212
DC3-09-0009	SIMPLE	A	1.67		1	1	03.14.2001	4.97	4.042	9.012	9.51	9.675	9.535	7.783	7.465
DC2-10-0010	SIMPLE	B	1.67		3	2	02.06.01	4.4011	2.904	7.3055	9.7235	9.763	9.748	7.0465	7.15375
DC3-07-0007	SIMPLE	B	1.67		1	1	02.12.01	5.0463	3.14	8.186	9.7695	9.688	9.715	7.32525	7.784
DC2-06-0006	SIMPLE	C	1.67		3	2	10.24.00	4.0574	3.514	7.5709	9.3515	8.75	8.866	7.945	7.3215
DC3-05-0005	SIMPLE	C	1.67		1	1	11.07.01	3.8964	3.307	7.2038	9.2615	9.288	8.998	7.631	7.46
DC2-04-0004A	SIMPLE	D	1.67		3	2	09.16.2000	4.4015	4.141	8.543	9.49725	8.325	9.654	7.3875	6.923
DC3-03-0003	SIMPLE	D	1.67		1	1	10.02.00	3.3327	2.988	9.071	9.67	9.463	9.771	7.4005	7.507
DC2-08-0008	SIMPLE	E	1.67		3	2	12.27.00	3.7059	3.684	7.3901	9.114	6.675	7.605	7.77075	7.82775
DC3-01-0001	SIMPLE	E	1.67		1	1	08.18.2000	2.6837	2.866	5.5499	8.73625	6.975	7.63	7.42175	7.548

DODGE NEON DYNAMOMETER DATA

(Page 2 of 6)

								THICKNESS						IVD
			GAL/	FUEL				PISTON		HEAD		AVERAGE		WEIGHT
TEST NUMBER	CYCLE	FUEL	HOUR	DIL, %	HEAD	BLOCK	EOT	MILS	MM	MILS	MM	MILS	MM	MG
DC2-07-0007	MAMA	A	2.17		2	2	11.08.00	5.393	0.137	2.314	0.059	3.853	0.098	9.6
DC3-04-0004	MAMA	A	2.17		2	1	10.21.00	6.310	0.160	5.972	0.152	6.141	0.156	4.4
DC2-05-0005	MAMA	B	2.17		2	2	10.09.00	4.939	0.125	4.829	0.123	4.884	0.124	4.4
DC3-08-0008	MAMA	B	2.17		2	1	02.27.2001	4.683	0.119	4.406	0.112	4.544	0.115	11.4
DC2-03-0003	MAMA	C	2.17		1	2	07.18.2000	4.040	0.103	4.973	0.126	4.506	0.114	543.3
DC3-02-0002	MAMA	C	2.17		2	1	9.14.2000	5.268	0.134	5.505	0.140	5.387	0.137	497.3
DC2-01-0001A	MAMA	D	2.17		3	2	02.21.2001	6.318	0.160	7.562	0.192	6.940	0.176	1.4
DC3-10-0010	MAMA	D	2.17		2	1	03.27.2001	6.368	0.162	6.968	0.177	6.668	0.169	3.4
DC2-09-0009	MAMA	E	2.17		2	2	01.15.01	3.755	0.095	5.296	0.135	4.526	0.115	522.2
DC3-06-0006A	MAMA	E	2.17		2	1	01.24.01	3.497	0.089	5.999	0.152	4.748	0.121	531.3
DC2-02-0002A	SIMPLE	A	1.67		2	2	03.08.2001	8.194	0.208	7.156	0.182	7.675	0.195	1.3
DC3-09-0009	SIMPLE	A	1.67		1	1	03.14.2001	6.280	0.160	6.630	0.168	6.455	0.164	1.0
DC2-10-0010	SIMPLE	B	1.67		3	2	02.06.01	6.623	0.168	6.562	0.167	6.593	0.167	1.4
DC3-07-0007	SIMPLE	B	1.67		1	1	02.12.01	6.848	0.174	6.919	0.176	6.883	0.175	6.4
DC2-06-0006	SIMPLE	C	1.67		3	2	10.24.00	6.047	0.154	4.414	0.112	5.230	0.133	28.8
DC3-05-0005	SIMPLE	C	1.67		1	1	11.07.01	5.341	0.136	6.198	0.157	5.770	0.147	4.8
DC2-04-0004A	SIMPLE	D	1.67		3	2	09.16.2000	6.087	0.155	7.510	0.191	6.798	0.173	4.7
DC3-03-0003	SIMPLE	D	1.67		1	1	10.02.00	4.939	0.125	4.829	0.123	4.884	0.173	4.4
DC2-08-0008	SIMPLE	E	1.67		3	2	12.27.00	4.997	0.127	7.551	0.192	6.274	0.159	497.0
DC3-01-0001	SIMPLE	E	1.67		1	1	08.18.2000	3.741	0.095	4.454	0.113	4.098	0.104	520.5

DODGE NEON DYNAMOMETER DATA
(Page 3 of 6)

								CCD			CCD				
			GAL/	FUEL				WEIGHTS			RATINGS				
TEST NUMBER	CYCLE	FUEL	HOUR	DIL, %	HEAD	BLOCK	EOT	PISTON	HEAD	TOTAL	RUNNER	TULIP	PORT	PISTON	CHAMBER
DC2-14-0014	MMASOAK	A	2.17		6	4	08.29.2001	5.089	3.03	8.118	9.726	9.638	9.677	8.02	7.961
DC3-11-0011A	MMASOAK	A	2.17		3	3	08.12.2001	2.698	1.526	4.225	9.603	9.538	9.587	7.5	7.866
DC3-16-0016	MMASOAK	A	2.17		3	3	11.12.2001	4.234	4.048	8.282	9.656	9.825	9.614	7.72	7.725
DC2-12-0012A	MMASOAK	C	2.17		6	4	07/28.2001	5.303	3.385	8.689	9.743	8.213	9.111	7.598	7.512
DC2-15-0015	MMASOAK	C	2.17		5	4	09.18.2001	4.675	3.416	8.091	9.609	8.263	9.36	8.318	7.518
DC3-13-0013	MMASOAK	C	2.17		3	3	09.11.2001	3.653	2.83	6.483	9.469	9.138	9.118	7.278	7.105
DC3-14-0014	MMASOAK	D	2.17		4	3	10.03.2001	3.088	2.671	5.759	9.688	9.888	9.786	7.944	7.925
DC2-11-0011	MMASOAK	D	2.17		5	4	06.15.2001	4.532	4.004	8.537	9.769	9.45	9.751	7.964	7.705
DC3-15-0015	MMASOAK	D	2.17		3	3	10.27.2001	3.931	3.494	7.425	9.817	9.863	9.806	8.019	7.916
DC2-13-0013	MMASOAK	E	2.17		5	4	08.12.2001	3.631	3.108	6.739	9.472	6.85	8.106	7.758	7.898
DC3-12-0012	MMASOAK	E	2.17		4	3	08.28.2001	2.675	2.605	5.279	9.167	7.38	8.517	8.315	8.229
DC2-16-0016	MMASOAK	E	2.17		6	4	10.04.2001	5.407	3.167	8.574	9.404	6.388	8.672	8.198	8.034
DC2-17-0017	MILDER	D	0.93		5	4	01.18.2002	5.538	5.036	10.574	9.595	9.25	9.58	7.133	7.152
DC2-18-0018	MILDER	E	0.93		6	4	02.05.2002	4.363	4.379	8.742	8.904	6.55	7.725	8.082	7.641
DC2-19-0019	MILDER	E	0.93		5	4	02.26.2002	3.813	4.708	8.521	8.553	6.913	6.981	7.645	7.098
DC2-20-0020	MILDER	D	0.93		6	4	03.18.2002	5.478	5.166	10.643	9.55	9.588	9.474	6.999	6.701

DODGE NEON DYNAMOMETER DATA
(Page 4 of 6)

								THICKNESS						IVD
			GAL/	FUEL				PISTON		HEAD		AVERAGE		WEIGHT
TEST NUMBER	CYCLE	FUEL	HOUR	DIL, %	HEAD	BLOCK	EOT	MILS	MM	MILS	MM	MILS	MM	MG
DC2-14-0014	MMASOAK	A	2.17		6	4	08.29.2001	6.155	0.156	5.723	0.145	5.939	0.151	9.5
DC3-11-0011A	MMASOAK	A	2.17		3	3	08.12.2001	3.858	0.098	1.355	0.034	2.607	0.066	2.1
DC3-16-0016	MMASOAK	A	2.17		3	3	11.12.2001	5.466	0.139	5.743	0.146	5.604	0.142	1.4
DC2-12-0012A	MMASOAK	C	2.17		6	4	07/28.2001	6.175	0.157	4.303	0.109	5.239	0.133	168.5
DC2-15-0015	MMASOAK	C	2.17		5	4	09.18.2001	5.202	0.132	5.808	0.148	5.505	0.140	131.6
DC3-13-0013	MMASOAK	C	2.17		3	3	09.11.2001	4.478	0.114	5.378	0.137	4.928	0.125	25.3
DC3-14-0014	MMASOAK	D	2.17		4	3	10.03.2001	4.464	0.113	4.341	0.110	4.403	0.112	7.0
DC2-11-0011	MMASOAK	D	2.17		5	4	06.15.2001	5.645	0.143	5.266	0.134	5.456	0.139	2.3
DC3-15-0015	MMASOAK	D	2.17		3	3	10.27.2001	5.240	0.133	5.385	0.137	5.313	0.135	6.3
DC2-13-0013	MMASOAK	E	2.17		5	4	08.12.2001	4.489	0.114	5.747	0.146	5.118	0.130	404.1
DC3-12-0012	MMASOAK	E	2.17		4	3	08.28.2001	3.095	0.079	4.873	0.124	3.984	0.101	342.4
DC2-16-0016	MMASOAK	E	2.17		6	4	10.04.2001	6.315	0.160	6.076	0.154	6.195	0.157	528.2
DC2-17-0017	MILDER	D	0.93		5	4	01.18.2002	7.039	0.179	8.072	0.205	7.556	0.192	3.9
DC2-18-0018	MILDER	E	0.93		6	4	02.05.2002	4.941	0.126	8.624	0.219	6.782	0.172	701.6
DC2-19-0019	MILDER	E	0.93		5	4	02.26.2002	5.142	0.131	7.871	0.200	6.506	0.165	749.3
DC2-20-0020	MILDER	D	0.93		6	4	03.18.2002	6.899	0.175	8.829	0.224	7.864	0.200	1.8

DODGE NEON DYNAMOMETER DATA
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								CCD			CCD				
			GAL/	FUEL				WEIGHTS			RATINGS				
TEST NUMBER	CYCLE	FUEL	HOUR	DIL, %	HEAD	BLOCK	EOT	PISTON	HEAD	TOTAL	RUNNER	TULIP	PORT	PISTON	CHAMBER
DC2-21-0021A	MILDER-10	E	1.38		7	4	07.10.2002	3.105	3.141	6.247	9.077	6.7	7.793	7.782	7.966
DC2-22-0022	MILDER-10	D	1.38		8	4	07.25.2002	4.461	4.184	8.644	9.846	9.2	9.698	7.567	7.688
DC2-23-0023	MILDER-10	D	1.38	1.6	7	4	08.12.2002	5.032	4.183	9.215	9.807	9.513	9.743	8.232	8.172
DC2-26-0026	MILDER-10	E	1.38	1.6	8	4	04.17.2003	4.15	3.414	7.564	9.182	6.725	8.19	7.565	7.262
DC2-27-0027	MILDER-10	E	1.38	1.6	7	4	05.01.2003	3.765	3.871	7.636	9.484	6.388	7.812	7.428	7.424
DC2-28-0028	MILDER-10	D	1.38	1.6	8	4	05.19.2003	4.593	3.606	8.199	9.628	9.525	9.648	7.12	7.109
DC2-29-0029A	MILDER-10	D	1.38	1.6	7	4	06.19.2003	4.692	4.343	9.035	9.69	9.588	9.685	7.183	7.088
DC2-30-0030	MILDER-10	A	1.38	1.6	8	4	07.09.2003	4.186	3.451	7.637	9.416	9.513	9.086	7.158	7.297
DC2-31-0031	MILDER-10	B	1.38	1.6	7	4	07.23.03	4.347	3.020	7.370	9.709	9.703	9.632	7.590	7.479
DC2-32-0032	MILDER-10	C	1.38	1.6	8	4	08.08.03	3.978	3.979	7.957	9.654	7.838	8.757	7.699	7.269
DC2-24-0024	SIM-15	D	1.27	1.3	8	4	09.04.2002	5.194	4.836	10.03	9.553	9.55	9.5	7.124	7.238
DC2-25-0025	SIM-15	E	1.27	1.6	7	4	09.28.2002	3.307	4.155	7.462	9.115	6.825	7.899	7.563	7.772

DODGE NEON DYNAMOMETER DATA
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								THICKNESS						IVD
			GAL/	FUEL				PISTON		HEAD		AVERAGE		WEIGHT
TEST NUMBER	CYCLE	FUEL	HOUR	DIL, %	HEAD	BLOCK	EOT	MILS	MM	MILS	MM	MILS	MM	MG
DC2-21-0021A	MILDER-10	E	1.38		7	4	07.10.2002	3.539	0.090	5.581	0.142	4.560	0.116	621.4
DC2-22-0022	MILDER-10	D	1.38		8	4	07.25.2002	5.170	0.131	6.193	0.157	5.681	0.144	3.8
DC2-23-0023	MILDER-10	D	1.38	1.6	7	4	08.12.2002	5.525	0.140	6.809	0.173	6.167	0.157	2.4
DC2-26-0026	MILDER-10	E	1.38	1.6	8	4	04.17.2003	3.760	0.096	6.555	0.166	5.157	0.131	777.1
DC2-27-0027	MILDER-10	E	1.38	1.6	7	4	05.01.2003	3.895	0.099	7.240	0.184	5.568	0.141	714.3
DC2-28-0028	MILDER-10	D	1.38	1.6	8	4	05.19.2003	15.138	0.384	6.962	0.177	11.050	0.281	8.0
DC2-29-0029A	MILDER-10	D	1.38	1.6	7	4	06.19.2003	5.059	0.129	7.324	0.186	6.192	0.157	11.2
DC2-30-0030	MILDER-10	A	1.38	1.6	8	4	07.09.2003	6.378	0.162	6.630	0.168	6.504	0.165	202.1
DC2-31-0031	MILDER-10	B	1.38	1.6	7	4	07.23.03	4.531	0.115	6.136	0.156	5.334	0.135	353.8
DC2-32-0032	MILDER-10	C	1.38	1.6	8	4	08.08.03	6.503	0.165	7.937	0.203	7.238	0.184	251.9
DC2-24-0024	SIM-15	D	1.27	1.3	8	4	09.04.2002	7.001	0.178	7.939	0.202	7.470	0.190	1.7
DC2-25-0025	SIM-15	E	1.27	1.6	7	4	09.28.2002	4.069	0.103	6.766	0.172	5.417	0.138	725.1

APPENDIX F

FORD TGA SAMPLE PREPARATION PROCEDURES

TGA Sample preparation

1. Prepare a minimum of 15 mg of unwashed gum by evaporating 50 ml of gasoline per ASTM D 381 method. Two or more beakers may be required to generate sufficient gum quantity. A maximum of 50 ml of gasoline shall be evaporated per beaker.

2. Add sufficient volume of methylene chloride to the gum beaker(s) and swirl gently to dissolve the gum.

3. Transfer sample into a tared vial with a pipette.

4. Repeat steps 2 and 3 until the methylene chloride is clear.

5. Evaporate the methylene chloride from each vial by air evaporation, steam bath or oven set at 40°C. Cover the vials with a paper towel or a loose fitting cap during evaporation.

6. Wash the inside wall of the vials with methylene chloride so that all gum residue collects on the bottom of the vial.

7. The vial(s) are warmed at 40° C to evaporate the methylene chloride. After solvent has evaporated completely, place the lids on the vials, and reweigh. The net increase in weight after adding the gum residue to the tared vial should not be significantly different from the total weight of unwashed gum collected in step 1.

8. Transfer the sample by adding an appropriate amount of methylene chloride (1-2 mL) to the vial.

9. Swirl sample in sealed vial for a few minutes to ensure that the sample is well mixed and all of the gum has dissolved. Note: The sample may collect on the vial wall if it is shaken too rapidly.

10. Transfer 10 -15 mg of gum to the TGA sample pan using sufficient solvent (1-2 mL of methylene chloride). Warm the pan at 40° C to evaporate the solvent. Record the weight of gum placed on the sample pan. Begin the temperature ramp.