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Air Conditioning Correction Factors in MOBILE6

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1 ABSTRACT

Revised air conditioning exhaust emission correction factors are being proposed for MOBILE6. The proposed factors are based on testing of 38 vehicles at two locations, using a test procedure meant to simulate air conditioning emission response under extreme “real world” ambient conditions. These factors are meant to predict emissions which would occur during full loading of the air conditioning system, and will be scaled down in MOBILE6 according to ambient conditions input by the user if appropriate. It was concluded that the data used in the development of the proposed factors adequately represents real world conditions, based on the results of a correlation vehicle tested at both test sites and a full environmental chamber. In general, emissions were found to increase significantly with air conditioning operation, but under some conditions HC and CO emissions decreased. For running emissions, speed-based correction factors were developed separately for Light-Duty Vehicles (LDV’s) and Light-Duty Trucks (LDT’s) for all pollutants; separate HC and CO corrections were also developed for high emitters. Correction factors for start driving were also assessed.

2 INTRODUCTION

Recent studies conducted primarily as part of the Supplemental Federal Test Procedure (SFTP) rulemaking development process indicate that vehicle fuel consumption and exhaust emissions increase substantially when the air conditioner is in operation. As the traditional method for accounting for the effects of air conditioner load - increasing dynamometer horsepower by 10% - is not adequate for characterizing this emission increase, new certification test procedures aimed at reducing emissions when the air conditioner is in operation were implemented as part of the SFTP rule. Air conditioning correction factors are included as an optional element of MOBILE5; however, these factors are based on testing performed in the early 1970's and are considered so outdated that the user is discouraged from using them in the MOBILE User’s Guide. Given the recent findings on air conditioning emissions, revised air conditioning correction factors are clearly needed.

This report presents the “full-usage” air conditioning exhaust correction factors proposed for MOBILE6. Full-usage correction factors are meant to represent the emission increase when the A/C system is inducing full system load on the vehicle, as would occur under extreme ambient (temperature, humidity and solar load) conditions. Since it not appropriate to apply these factors to all ambient conditions, MOBILE6 will scale these factors down based on the ambient conditions under which the model is being run (the development of appropriate scaling factors is discussed in Report Number M6.ACE.001, "Air Conditioning Activity Effects in MOBILE6"). Discussion in this report includes the testing used to generate A/C emission data, correlation between the two test sites and with expected real-world results, and the development of the full-usage correction factors. It should be noted that the correction factors presented in this report apply to vehicles which do not comply with the SFTP requirement. The treatment of air conditioning correction factors for vehicles complying with the SFTP requirement will be addressed in a separate report.

3 TESTING

3.1 Vehicles

The data used for this analysis was generated through testing performed at EPA’s National Vehicle and Fuel Emissions Laboratory and through an EPA contractor, Automotive Testing Laboratories (ATL), in East Liberty, Ohio. 26 vehicles were tested at EPA and 12 were tested at ATL, including one vehicle tested at both locations for correlation purposes (treated as two separate vehicles for the purpose of this analysis). A list of the vehicles tested is contained in Table 1. The sample consisted of 1990 and later vehicles categorized as follows: 24 cars / 14 trucks, 32 Ported Fuel Injection (PFI) / 6 Throttle-Body Injection (TBI), and 28 Tier 0 / 10 Tier 1. Each vehicle was designated either as a “normal” emitter or “high” emitter using the following emission cutpoints over the Running LA4[1] : 0.8 g/mi HC, 15.0 g/mi CO and 2.0 g/mi NOx (the cutpoints were applied independently for each pollutant, so that a vehicle could be a high emitter for HC and a normal emitter for NOx). These cutpoints yielded five high emitters for HC, three for CO and two for NOx.

3.2 Test Procedure

EPA's new air conditioning test procedure is based on use of a full environmental chamber at 95° F, 40% Relative Humidity and full solar load (850 Watts/Meter^2). This type of facility was not available to EPA at the time of testing, so use of a procedure which simulated these conditions was required. A/C-on tests were conducted in a standard emission test cell at 95° F and 50

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[1] “Running LA4" emissions were derived from the combination of emissions from Bag 2 and a 505 cycle run warmed-up (i.e. without a soak). More detail on this calculation can be found in MOBILE6 Report No. M6.STE.002, “The Determination of Hot Running Emissions from FTP Bag Emissions"

grains/pound of humidity with standard cooling and the driver window down. The A/C system was set according to the SFTP requirements; maximum A/C and blower setting with recirculation mode if so equipped. Rather than attempting to represent a condition that would actually occur in-use, this simulation is meant solely to induce the level of A/C system load on the vehicle which would occur in the real world under extreme ambient conditions. Operating with the driver window down and with standard cooling is meant to compensate for the lower humidity level and lack of solar load inherent in the standard cell. This simulation method showed adequate correlation with SFTP environmental cell conditions during the development of the SFTP rulemaking[2], and is a straightforward way to approximate real-world air conditioning emissions using a standard cell setup. A/C-off tests were run in standard FTP ambient conditions (75° F, 50 grains/pound humidity).

The vehicles were run in a warmed-up condition over EPA's facility-specific inventory cycles[3], ARB's Unified Cycle (the LA92), and the New York City Cycle one time each with the A/C on and A/C off. A cold start ST01[4] cycle was also run in both conditions for the purpose of assessing start A/C factors (information on all driving cycles used in this test program is shown in Table 2). The EPA tests were run on a 48-inch electric dynamometer, while the ATL testing used a twin 20-inch electric dynamometer; all tests were run without the 10% A/C load adjustment factor typical to standard emission tests. Both bag and modal data were collected.

3.3 Overall Results

As with previous versions of the model, MOBILE6 will contain correction factors which estimate the emission impact of changes in temperature. Emissions at temperatures higher than 75° F will be determined in the model first by applying a base temperature correction, then applying the A/C correction factor appropriate for that temperature. A/C correction factors must be developed separately from the baseline temperature corrections in order to avoid double-counting temperature impacts. For this analysis, therefore, the A/C-off results were corrected from the temperature the test was conducted (nominally 75°, although minor variability is common) to the A/C-on temperature (nominally 95°) for each paired test. Since MOBILE6 temperature correction factors will not change from the MOBILE5 corrections, MOBILE5

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[2] Results from a correlation program between this simulation and a full environmental chamber over a sample of six Tier 1 vehicles can be found in AAMA/AIAM's comments to EPA on the proposed SFTP rulemaking (EPA Docket No. A-92-64 Item IV-D-10).

[3] For detail on the development of EPA's facility-specific inventory cycles, see MOBILE6 Report No. M6.SPD.001, "Development of Speed Correction Cycles"

[4] ST01 is a 1.4 mile cycle developed to specifically characterize driving behavior following startup. The cycle was developed from an in-use driving survey conducted in Baltimore, Spokane and Los Angeles as part of the SFTP rulemaking process.

temperature corrections were used[5]. The Bag 2 corrections were used for all running tests, and Bag 1 corrections were used for the cold start ST01 test[6].

Once the temperature correction was applied, the A/C impact was analyzed by taking the ratio of emissions with the A/C on to corrected emission levels with the A/C off results (referred to throughout the report as the "A/C ratio"). This ratio was based not on each individual vehicle, but on the average A/C on and A/C off levels over all vehicles for each driving cycle. Results of this analysis on the running cycles over all vehicles are shown in Figures 1-4 for fuel consumption, HC, CO and NOx; in these figures, the driving cycles are ordered from lowest (NYCC) to highest (FWHS) average speed. Although a more detailed analysis is covered in Section 5, these figures highlight some general trends that shape the development of running correction factors:

Fuel Consumption and NOx: Increases in fuel consumption[7] and NOx generally result from the added load placed on the engine by the air conditioning system when the A/C compressor (which is propelled by the engine) is engaged. Figures 1 and 2 show a consistent increase over all cycles, with a strong dependency on average speed. In general A/C load is fairly constant over all operation, so the relative additional load placed on the engine depends on the loading condition of the engine itself. Larger relative increases in engine load due to air conditioning occur at lower speeds, while at higher speeds the relative additional load placed on the engine by the air conditioning system is smaller. This results in a decreasing A/C ratio as average cycle speed increases.

HC and CO: Although the changes in relative A/C loading (and hence fuel consumption) mentioned above can also drive increases in HC and CO, more significant increases are usually the result of fuel enrichment. Excess fuel enrichment can result from the added load placed on the engine and/or fuel calibrations that simply add fuel because the air conditioning system is in operation. Although not the case for every vehicle, the effects of this enrichment on emissions (particularly CO) from the vehicles that do experience excess fuel enrichment are so large that average fleet emissions are increased significantly. Figure 3 shows A/C ratio for HC; the ratio is higher at the low and high ends of the speed range, but actually drops below 1.0 in the mid range. One explanation of this is that increased combustion temperatures resulting from higher engine load reduce HC emissions in some situations. Figure 4 shows higher ratios for CO but less dependence on speed. This suggests the stronger role of vehicle calibration in driving the CO

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[5] The temperature corrections will be modified to accommodate the start/running split new to MOBILE6, but the base corrections will not change. The start/running split has not be developed, so for this analysis the MOBILE5 Bag corrections were applied.

[6] MOBILE5 temperature correction factors can be found in "Compilation of Air Pollutant Emission Factors, Volume II - Mobile Sources" (AP-42), Page H-24

[7] Fuel consumption correction factors are presented in this report primarily because of the proposed treatment of CO for vehicles complying with the SFTP requirement, to be discussed in a future report.

emission increase. One caveat of both the overall HC and CO results shown here is that they are largely driven by the high emitters in the sample, which (as discussed in Section 5) had lower A/C ratios. The HC and CO increases for normal emitters were found to be significantly larger than those shown in Figures 3 and 4.

4 CORRELATION

Preliminary data presented at the October 1997 MOBILE6 workshop indicated a potential offset between the results from vehicles tested at EPA and those tested at ATL[8]. A/C ratios from the ATL sample were lower than EPA on average for fuel consumption and all three pollutants. This raised a question about whether the simulation as conducted at ATL induced comparable A/C system loading to the procedure as conducted at EPA. A related issue is whether loading induced by the simulation as conducted at either site could be considered "full-usage", as defined for the purpose of this analysis by the conditions used for the SFTP certification test (95 ° F, 40% Relative Humidity, 850 W/m^2 solar load). To investigate both issues, a correlation vehicle was run over all test cycles using the simulation procedure at EPA and ATL, and on a subset of cycles under the SFTP test conditions at GM's environmental chamber in Rochester, New York. This vehicle was instrumented to monitor A/C compressor cycling and compressor pressures (high and low side) on a real-time basis to gain a fuller sense of how the vehicle's A/C system was loaded at each location.

Emission results for the four cycles tested at all three locations are shown in Table 3. There is quite a bit of variability in the HC, CO and NOx results, making it difficult to discern any clear trend. Judging from the large swings in each pollutant, it appears that the vehicle went into enrichment sporadically between sites, resulting in a wide range of A/C ratio results across the test matrix. Thus, it is difficult to draw conclusions from the emission data (and particularly the A/C ratios) alone. The correlation analysis therefore focussed on fuel consumption (carbon) ratio and compressor operation to determine whether a difference in the relative loading placed on the vehicle between the three sites can be distinguished. The carbon ratio results in Table 3 show the ATL results to be slightly lower than EPA for each cycle.   However, the EPA and ATL carbon ratios are higher than the GM ratio for three of the four cycles, and the three locations show relatively consistent carbon ratios over the New York City, Unified and Arterial cycles. The exception to the latter point is the High Speed Freeway cycle, for which the GM ratio (as well as the A/C-on carbon levels) are significantly lower than EPA or ATL.

Table 4 contains compressor behavior data, expressed in terms of the compressor fraction (the fraction of time the compressor in engaged during the test), and average high and low side compressor pressures, on which compressor torque in based.   The data indicate that a) the compressor was engaged at all locations 97% or more of the time on each of the cycles, and b) for the New York City, Unified and Arterial cycles a strong difference is not observed in the compressor pressures. The exception again is the High Speed Freeway cycle, for which the GM

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[8] "A/C Effects in MOBILE6", presentation at the October 1997 MOBILE6 workshop

data shows significantly lower compressor pressures than ATL or EPA. From these data and the fuel consumption results, it is apparent that the A/C system load on the high speed freeway cycle in the full environmental cell was much less than that produced by the simulation at EPA or ATL. The most plausible explanation for this is the use of a variable speed fan in the full environmental cell, which would create a much higher airflow than produced by the standard one-speed fan used on the simulation. Higher air flow across the vehicle's A/C system can increase system efficiency, reducing relative load demand on the engine. This suggests that the simulation could be overpredicting A/C loading (and hence emissions) at the higher speed levels; however, this effect does not appear in the overall LA92 results, a cycle which also contains significant high speed operation. Unfortunately sufficient data does not exist over high speed operation with representative air flow to make a more full assessment; further research will be needed to address this issue.

From the fuel consumption and compressor data it was concluded for the purposes of this study that despite observed emission differences between ATL and EPA, the vehicles were adequately loaded at both sites to represent full-usage conditions. Therefore, no vehicles will be excluded from the analysis and the emission results from the dataset will be used directly (i.e. with no scaling) to develop the full-usage correction factors.

5 RUNNING CORRECTION FACTORS

The development of running correction factors requires analysis of what vehicle groupings merit separate treatment. The factors considered were: vehicle class (i.e. cars vs. trucks), emission standard, emitter class and technology (i.e. fuel injection). In addition, average cycle speed and facility type were investigated. Simple factorial Analysis of Variance (ANOVA) was used for initial screening of each factor, followed by a more detailed analysis to determine the appropriate stratifications given sample size and technical merit. A discussion of this investigation follows for each pollutant.

5.1 NOx

ANOVA was performed over the entire vehicle sample with NOx ratio as the dependent versus speed, facility , technology, class and emitter class; significance results are shown in Table 5. Using a significance level of 0.05 as a cutoff, the variables considered for further analysis were speed, technology, class and emitter level. Each are discussed below:

Speed: As discussed in Section 3, the relative load placed on the engine by the air conditioner is high at lower average speeds and low at higher speeds. As shown in Figure 2, the NOx A/C ratio tracks this trend as well. As this trend is consistent across vehicles and a technical basis exists for it, NOx correction factors will be expressed as a function of speed.

Class: A distinct difference in NOx A/C ratio between vehicles and trucks was observed. As shown in Figures 5 and 6, the ratio for fuel consumption and NOx is lower for trucks, particularly at the lower speed ranges. The basis for this is that in general the demand placed on a more powerful truck engine by the A/C system is relatively small compared to a similar load placed on a passenger car engine. In addition, lower cabin volumes on some trucks could reduce A/C demand (although the recent proliferation of sport utilities and minivans would seem to counteract this). Based on this observation, separate NOx correction factors will be developed for LDV's and LDT's.

A second question is whether LDT classes should be subdivided. Graphical analysis of NOx ratio with trucks broken down into the MOBILE5 definition of trucks (LDT1 up to 6000 GVW, LDT2 up to 8500 GVW) do indicate a possible difference between the truck classes; LDT1's are more similar to LDV's, while LDT2's are much lower. However, because the LDT2 results are based on a sample of only four trucks, for sample robustness the truck classes will not be subdivided. Since MOBILE6 will switch from the MOBILE5 truck definition to the more subdivided certification truck classes (LDT1 through 4), the "LDV" equation will be applied to LDV's and certification LDT1's, and the "LDT" equation will be applied to certification LDT2's, 3's and 4's (this will be applied as a general rule for HC and CO also).

Technology: Since all of the vehicles tested were equipped with a 3-way catalyst, the technology breakdown in terms of MOBILE stratification relates to whether the vehicles was equipped with throttle-body fuel injection (TBI) or ported fuel injection (PFI). Although ANOVA results show significance, the sample size of TBI's is small and there is a strong interaction with vehicle class. A technical basis for why NOx emission increase would be different between TBI and PFI is not apparent. In the interest of sample robustness and concern with the potential error introduced by developing separate factors for fuel injection based on limited data, NOx correction factors will not be subdivided based on technology.

Emitter Class: Subdividing factors by emitter class is attractive because a) it is reasonable to expect that vehicles with very high baseline emissions would see less relative increase due to A/C operation, and b) averaging emissions from high emitters with normal emitters would strongly impact overall sample average and ratio calculations for normal emitters. However, there were only two NOx high emitters in the sample (one LDV and one LDT), and the behavior of each was drastically different; the truck tracked the behavior of normal emitters, while the vehicle showed little A/C impact across the speed range. Because of the small sample size and disparity in response of the two high emitters, it was decided not to break out factors by emitter class for NOx.

The proposed NOx running correction factor equations were developed by taking a quadratic regression over the sample average ratio of each cycle versus speed for vehicles and trucks. This curve form is favored because it fits data trends well without abnormal behavior at the low and high ends of the speed range. As shown in Figure 6, this results in a curve which dips to a minimum level around 45-55 mph before turning upward at the high end. The option of using a straight average based on the high speed results above 40 mph was considered rather than using the upward curve form. However, because both the NOx (for trucks) and fuel consumption data suggests that directionally an upward trend it correct, the equation form will be applied as fitted. The coefficients are shown in Table 6. Because the LDT curve surpasses the LDV curve in the high speed range, the LDT equation will be set equal to the LDV curve at the point of intersection (roughly 57 mph); occurrence of a higher LDT A/C ratio is judged to be an artifact of curve extrapolation, and will be addressed in this manner as a general rule.

5.2 NMHC

ANOVA results for NMHC indicate significance to the 0.05 level for speed, technology, class and emission standard (Table 5). Splitting by technology was ruled out, again for small sample size and interaction with vehicle class. Graphical analysis of NMHC ratio by standard class indicated that the observed difference was likely driven by a large disparity between average Tier 0 and Tier 1 ratios on a limited number of cycles, with no consistency as to which standard class had the higher ratio. The majority of cycles showed no observable offset in ratios between the standard classes; for this reason, it was decided not to pursue standard class as an additional stratification.

For sample robustness, class will be divided into LDV and LDT in a similar manner as NOx. Figure 7 shows NMHC ratio versus average cycle speed for normal emitters in both classes, fit with a quadratic curve form. For both classes the data indicate higher ratios at the low and high ends with a dip in the middle. For trucks, the NMHC ratio is less than 1.0 in the mid range. This phenomena is consistent across many vehicles, likely the result of improved combustion due to higher combustion temperatures and/or catalyst oxidation due to shifts in air fuel ratio (for cases when enrichment is not introduced with A/C).

Although emitter category did not show significance to the 0.05 level, graphical analysis shows a significant drop in NMHC ratio for high emitters versus normal emitters, based on a sample of five high emitting vehicles (Figure 8). The technical basis for this observation is that it is more likely that HC high emitters are operating with enrichment and/or very low catalyst efficiency without air conditioning. There is less opportunity for emissions to increase significantly when the air conditioning system is operating, since added enrichment or drops in conversion efficiency with the A/C on won’t have the same relative impact. Because of the observed difference and technical basis behind the difference, high emitters will be model separately from normal emitters for NMHC.

The proposed NMHC correction factors were developed by vehicle class and emitter class by fitting a quadratic function to the sample averages by average speed (shown in Figures 7 and 8); the proposed coefficients are shown in Table 6. The low end of the normal emitter LDT curve is higher than the LDV curve, an artifact of extrapolation. The LDT model will therefore be set to equal to the LDV model between 0 mph and the point of intersection (approximately 8 mph).

5.3 CO

ANOVA results for CO ratio do not indicate significance for any of the parameters of interest. However, vehicle class becomes significant below the 0.05 level when the two MOBILE5-based LDT classes are split. Graphical analysis indicated a distinct trend for each class (LDV, MOBILE5 LDT1 and LDT2). The LDT1 ratio is consistently less than the LDV ratio, while the LDT2 is also generally lower but somewhat erratic. For sample robustness, a single LDT equation was again developed. As shown in Figure 9, there is a marked difference in CO ratio between the two classes.

Although emitter class was not significant in the ANOVA result, CO emission levels for high emitters were so large and the CO ratio for these vehicles so much smaller than normals that separate treatment was judged to be necessary. Two LDT high emitter and one LDV high emitter were included in the sample. Because all had similar CO ratio behavior they were combined into a single high emitter equation form (Figure 10). The proposed coefficients for CO are found in Table 6.

6 START CORRECTION FACTORS

A primary change between MOBILE6 and MOBILE5 is the separation of FTP-based emissions into start and running components. This change draws a distinction between start emissions and emissions over start driving. Running emissions will represent not only emissions over warmed-up operation, but the baseline emissions inherent in start driving; start emissions will be defined as the incremental emission increase above this baseline which occurs during start driving. Total emissions over start driving, therefore, will be comprised of the baseline running emissions plus incremental start emissions. In terms of air conditioning correction factors, the running correction factors developed in Section 5 will carry over to start driving to the extent that start driving emissions are comprised of the baseline running component. The pertinent issue for start air conditioning correction factors is therefore whether an A/C impact exists on the incremental start component as well.

Data required to make this assessment based on the methodology used in the development of base start and running emission factors[9] were not gathered as part of the air conditioning test program. An assessment was therefore made by analyzing the ratio for each pollutant over a cold start ST01 run with the A/C on and off, shown for relevant stratifications in Table 7. The NOx and fuel consumption results indicate there is an increase over start driving due to air conditioning, but smaller (by 13% for LDV’s, 7% for LDT’s) than the impact over running operation at the average speed of the ST02 cycle (20.2 mph). It is presumed from this result that the NOx ratio observed over ST01 is attributable solely to the baseline running component, with no A/C-related increase occurring on the start increment. The cold start NOx ratio is not

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[9] This methodology referred to is the separation of FTP emissions into Start and Running components as described in MOBILE6 Report No. M6.STE.002, “The Determination of Hot Running Emissions from FTP Bag Emissions"

substantially lower than the corresponding running NOx ratio presumably because the difference between cold start and warmed-up NOx emissions is relatively small (hence the contribution of the running component to overall NOx start emissions is large). Based on this presumption, a NOx correction factor for the incremental start component is not proposed for MOBILE6.

HC and CO results vary somewhat, particularly across emitter class. However, for the most part the ratios are closer to one than for the running correction factors. Cold start HC and CO emissions are dominated by emissions incurred by startup enrichment, and the drop in A/C ratios for both pollutants between running and cold start is attributed to this. Under cold start enrichment the air-fuel ratio will likely not change due to air conditioner operation and/or increased engine load, so increased HC or CO emissions are not expected over the start component. It is therefore proposed that no A/C correction factor be applied to the HC or CO start components.

It is important to note that although air conditioning correction factors are not proposed for the start components of any pollutant, air conditioning emissions over start driving will be estimated by MOBILE6. Because the running correction factors are carried over to start driving, they will be applied to the extent running emissions contribute to overall start emissions. This will be true for all starts, including those following “intermediate” soak durations in which the engine and/or catalyst are partially warmed up. For the most part, the contribution of running emissions (and hence the influence of the running air conditioning correction factors) will become greater as the soak duration shortens.

7 ACKNOWLEDGMENTS

Several individuals contributed considerable time and resources to gathering and analyzing the data presented here. Carl Fulper, Carl Scarbro, Dave Boshenek and Manish Patel of OMS designed and implemented the test program and developed the attendant dataset. Steve Baldus and Kevin Cullen of GM made GM’s environmental chamber available and coordinated testing at that facility. Janet Kremer of OMS assisted in coordinating testing at GM and analyzed correlation vehicle results.

Table 1 - Vehicle Sample

Site	Year	Vehicle	Class	Fuel	Std	Emit*
ATL	91	CHEVROLET CAVALIER	LDV	TBI	Tier 0	N/N/N
ATL	91	FORD ECONOLINE 150	LDT2	PFI	Tier 0	H/H/N
ATL	91	FORD ESCORT	LDV	PFI	Tier 0	H/N/H
ATL	91	PLYMOUTH VOYAGER	LDT1	TBI	Tier 0	N/N/N
ATL	91	CHEVROLET ASTRO VAN	LDT1	TBI	Tier 0	H/N/N
ATL	93	CHEVROLET CORSICA	LDV	PFI	Tier 0	N/N/N
ATL	93	CHEVROLET S10	LDT1	TBI	Tier 0	N/N/N
ATL	93	TOYOTA CAMRY	LDV	PFI	Tier 0	N/N/N
ATL	93	HONDA ACCORD	LDV	PFI	Tier 0	N/N/N
ATL	90	NISSAN MAXIMA	LDV	PFI	Tier 0	N/N/N
ATL	93	EAGLE SUMMIT	LDV	PFI	Tier 0	N/N/N
EPA	92	TOYOTA COROLLA	LDV	PFI	Tier 0	N/N/N
EPA	96	HONDA ACCORD	LDV	PFI	Tier 1	N/N/N
EPA	92	SATURN SL	LDV	TBI	Tier 0	N/N/N
EPA	92	CHEVROLET BERETTA	LDV	PFI	Tier 0	H/H/N
EPA	94	FORD F150	LDT2	PFI	Tier 0	N/N/N
EPA	96	FORD F150	LDT2	PFI	Tier 1	N/N/N
EPA	92	MAZDA PROTEGE	LDV	PFI	Tier 0	N/N/N
EPA	96	CHEVROLET LUMINA	LDV	PFI	Tier 1	N/N/N
EPA	92	CHEVROLET CAVALIER	LDV	PFI	Tier 0	N/N/N
EPA	96	FORD RANGER	LDT1	PFI	Tier 1	N/N/N
EPA	90	JEEP CHEROKEE	LDT1	PFI	Tier 0	H/H/H
EPA	90	CHEVROLET SUBURBAN	LDT2	TBI	Tier 0	N/N/N
EPA	94	CHRYSLER LHS	LDV	PFI	Tier 0	N/N/N
EPA	96	HONDA CIVIC	LDV	PFI	Tier 1	N/N/N
EPA	94	CHEVROLET ASTRO VAN	LDT1	PFI	Tier 0	N/N/N
EPA	94	SATURN SL	LDV	PFI	Tier 0	N/N/N
EPA	94	HYUNDAI ELAN	LDV	PFI	Tier 0	N/N/N
EPA	92	CHEVROLET LUMINA VAN	LDT1	PFI	Tier 0	N/N/N
EPA	94	FORD ESCORT	LDV	PFI	Tier 1	N/N/N
EPA	90	PLYMOUTH VOYAGER	LDT1	PFI	Tier 0	N/N/N
EPA	92	CHEVROLET LUMINA	LDV	PFI	Tier 0	N/N/N
EPA	96	FORD EXPLORER	LDT1	PFI	Tier 1	N/N/N
EPA	94	PONTIAC TRANSPORT	LDT1	PFI	Tier 1	N/N/N
EPA	96	TOYOTA CAMRY	LDV	PFI	Tier 1	N/N/N
EPA	90	DODGE DYNASTY	LDV	PFI	Tier 0	N/N/N
BOTH	96	PONTIAC GRAND PRIX	LDV	PFI	Tier 1	N/N/N

*HC/CO/NOx

Table 2 - Test Cycles

Cycle	**Description**	**Distance (miles)**	**Average Speed (mph)**	**Max Speed (mph)**	**Max Accel (mph/sec)**
NYCC	New York City Cycle	1.18	7.1	27.7	6.0
LOCL	Local Roadways	7.24	12.9	38.3	3.7
ARTE	Arterial **L**evel **O**f **S**ervice E-F	1.62	11.6	39.9	5.8
ARTC	Arterial LOS C-D	3.35	19.2	49.5	5.7
ARTA	Arterial LOS A-B	5.06	24.7	58.9	5.0
FWYG	Freeway LOS G	1.42	13.1	35.7	3.8
FWYF	Freeway LOS F	2.28	18.6	49.9	6.9
FWYE	Freeway LOS E	3.85	30.5	63.0	5.3
FWYD	Freeway LOS D	5.95	52.9	70.6	2.3
FWAC	Freeway LOS A-C	8.54	59.7	73.1	3.4
FWHS	Freeway High Speed	10.70	63.2	74.7	2.7
RAMP	Freeway Ramp	2.56	34.7	60.2	5.7
AREA	Non-Freeway Area-Wide	7.25	19.4	52.3	6.4
LA92	California “Unified” Cycle	9.81	24.6	67.2	6.9
ST01	Start Cycle	1.39	20.2	41.0	5.1

Table 3 - Correlation Vehicle Emission Results (g/mi)

		NMHC			**CO**			**NOx**			**Carbon**		
		Off	**On**	**Ratio**	**Off**	**On**	**Ratio**	**Off**	**On**	**Ratio**	**Off**	**On**	**Ratio**
NYCC	*ATL*	0.07	0.67	9.39	1.36	4.34	3.19	0.03	0.33	10.20	214.1	281.6	1.31
	EPA	0.07	0.07	1.03	0.98	3.32	3.39	0.11	0.25	2.15	208.6	275.4	1.32
	GM	0.06	0.07	1.25	0.60	7.71	12.94	0.11	0.28	2.52	217.8	283.5	1.30
LA92	*ATL*	0.04	0.10	2.76	0.39	7.92	20.35	0.38	0.21	0.55	115.3	138.7	1.20
	EPA	0.02	0.02	0.94	0.15	0.53	3.52	0.38	0.51	1.34	110.1	133.0	1.21
	GM	0.04	0.03	0.61	0.54	1.83	3.37	0.67	1.04	1.55	216.8	267.2	1.23
FWHS	*ATL*	0.08	1.32	15.72	2.82	100.04	35.47	0.25	0.03	0.12	88.2	120.7	1.37
	EPA	0.05	1.33	24.23	4.63	112.24	24.26	0.22	0.00	0.01	82.7	120.0	1.45
	GM	0.02	0.03	1.75	0.82	2.41	2.94	0.30	0.62	2.05	82.0	85.9	1.05
ARTC	*ATL*	0.04	0.04	1.11	1.70	1.41	0.83	0.11	0.16	1.48	120.0	145.3	1.21
	EPA	0.03	0.05	1.48	1.41	3.00	2.13	0.13	0.28	2.14	116.7	144.4	1.24
	GM	0.01	0.03	2.83	0.33	2.99	9.15	0.19	0.37	1.94	120.2	144.5	1.20

Table 4 - Correlation Vehicle Compressor Behavior

		Compressor Fraction	**Average High Pressure (lb/in^2)**	**Average Low Pressure (lb/in^2)**
NYCC	*ATL*	1.00	311.5	49.7
	EPA	0.99	306.4	58.1
	GM	0.97	320.9	44.5
LA92	*ATL*	0.99	334.2	48.2
	EPA	0.97	339.4	57.9
	GM	0.99	312.1	40.3
FWHS	*ATL*	1.00	361.1	43.7
	EPA	0.99	367.3	50.3
	GM	1.02	264.8	34.3
ARTC	*ATL*	1.00	310.7	46.4
	EPA	0.98	315.3	54.7
	GM	0.99	310.8	39.0

Table 5 - ANOVA results for A/C Ratio (Significance by Factor)

Factor	Fuel	NOx	NMHC	CO
Speed	0.000	0.000	0.004	0.526
Facility	0.057	0.067	0.104	0.672
Technology	0.000	0.018	0.023	0.287
Standard	0.000	0.616	0.041	0.678
Emitter	n/a	0.019	0.076	0.131
Class	0.000	0.003	0.000	0.015*

* MOB5 LDT1 & 2 split

Table 6 - Full-Usage A/C Emission Factor Equations
(Equations apply to Running operation unless otherwise indicated)

Emission Factor = Constant + a*(Speed) + b*(Speed^2)

Pollutant/Class/Emitter	Constant	a	b	R^2	Comment
Fuel/LDV/All	1.34	-0.006134	0.000053	0.92	Cert LDV/LDT1*
Fuel/LDT/All	1.27	-0.004939	0.000048	0.78	Cert LDT2/3/4*
NOx/LDV/All	2.04	-0.032641	0.000299	0.80	
NOx/LDT/All	1.66	-0.022284	0.000236	0.68	LDT= LDV ≥ 57 mph
NMHC/LDV/Low	1.70	-0.027339	0.000575	0.44	
NMHC/LDT/Low	2.07	-0.076717	0.001193	0.26	LDT=LDV≤ 8 mph
NMHC/All/High	1.37	-0.024791	0.000286	0.58	
CO/LDV/Low	2.59	-0.026773	0.006090	0.25	
CO/LDT/Low	2.21	-0.067114	0.001058	0.33	
CO/All/High	1.41	-0.017942	0.000165	0.54	

*applies to HC,CO,NOx as well

Table 7 - Cold Start ST01 A/C Ratios
(average cycle speed = 20.2 mph)

	LDV		LDT	
	Normal	**High**	**Normal**	**High**
Fuel	1.17	n/a	1.13	n/a
NOx	1.24	n/a	1.19	n/a
NMHC	0.96	1.29	1.05	0.97
CO	0.95	1.60	1.17	0.99

Figure 1 - Fuel Ratio by Cycle (sample average)

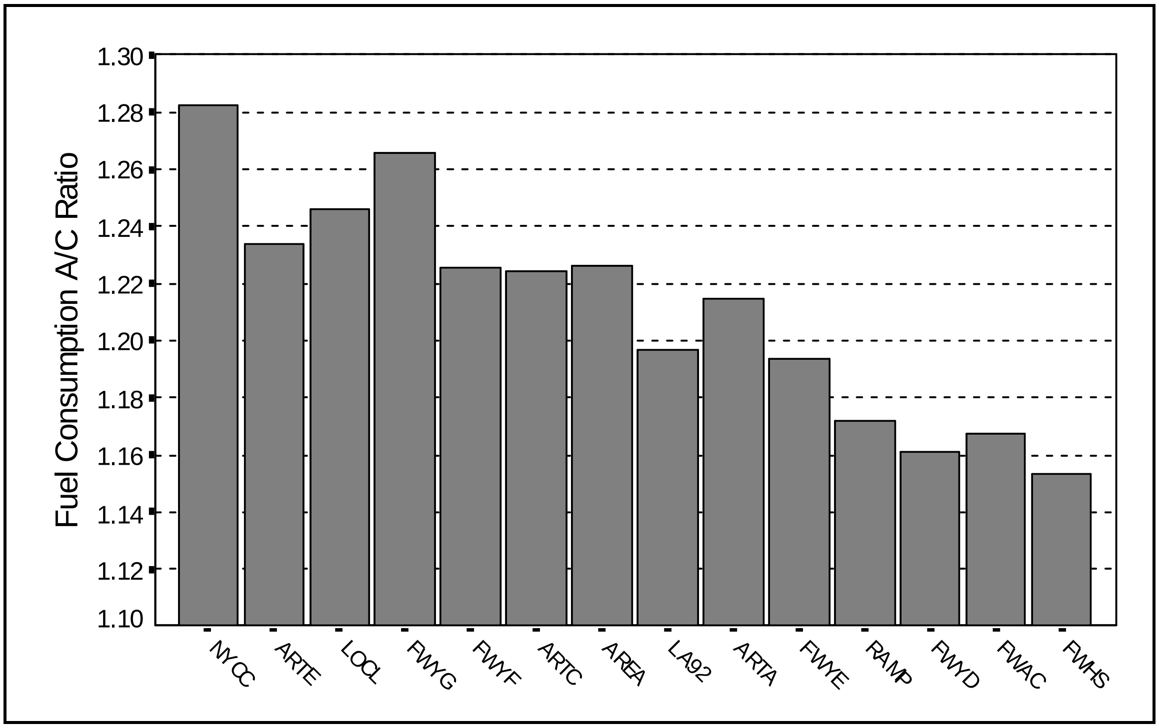

Figure 2 - NOx Ratio by Cycle (sample average)

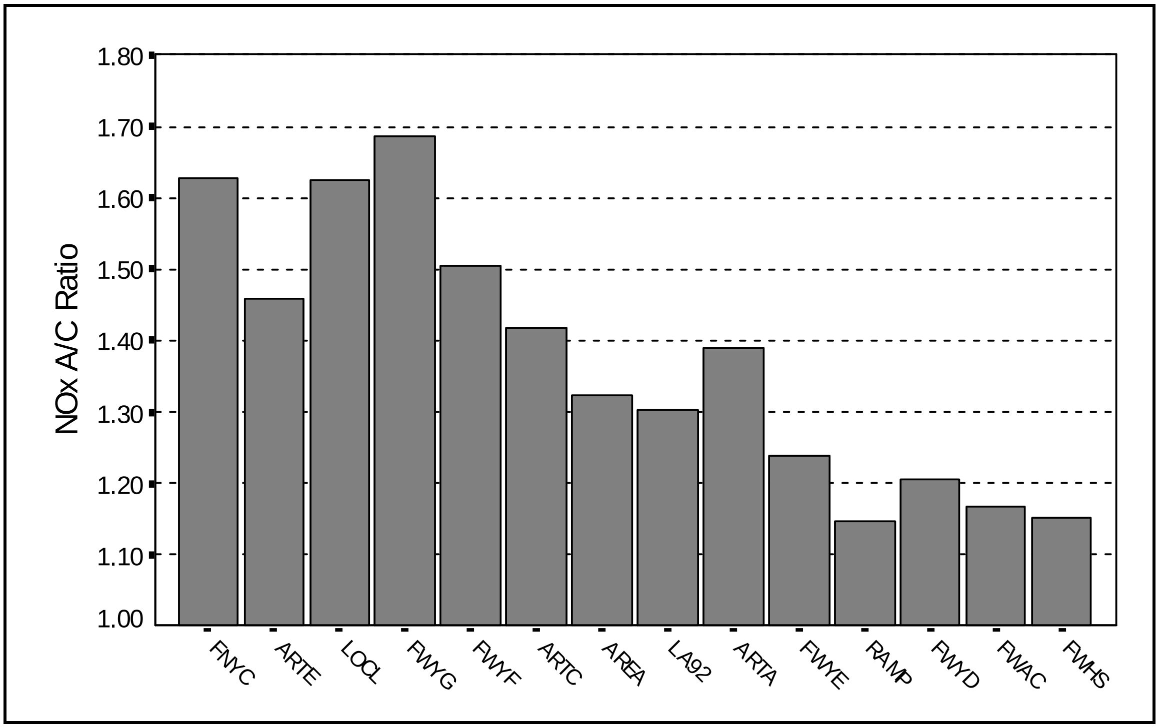

Figure 3 - HC Ratio by Cycle (sample average)

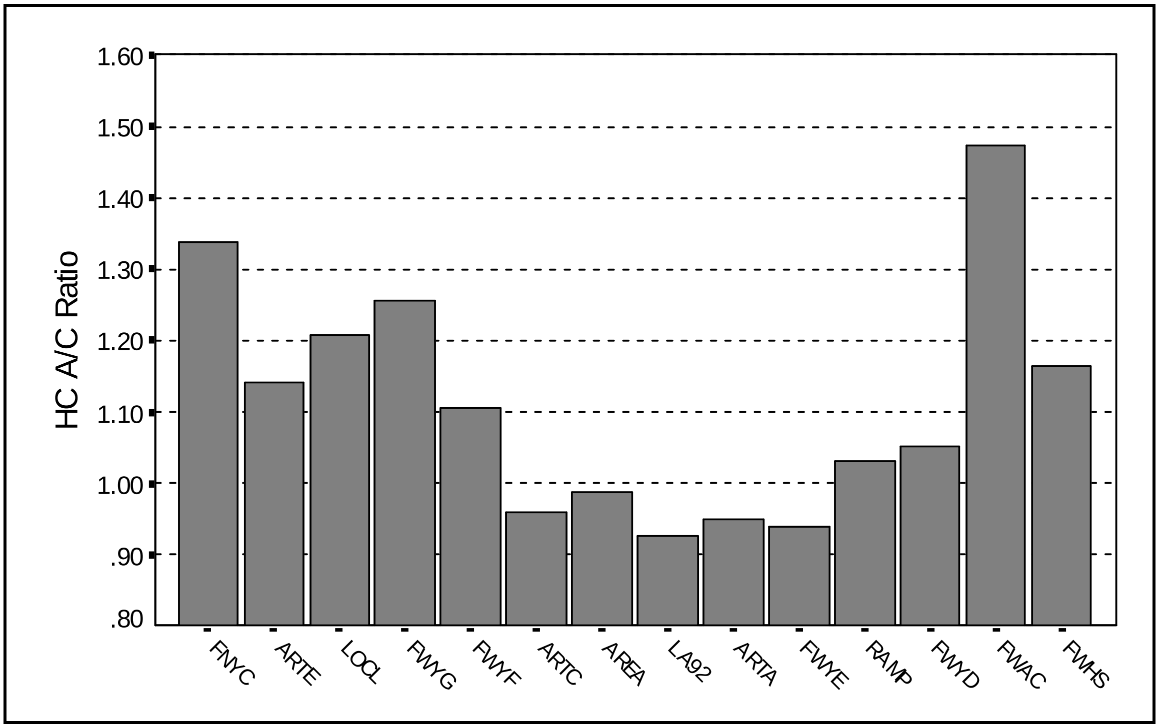

Figure 4 - CO Ratio by Cycle (sample average)

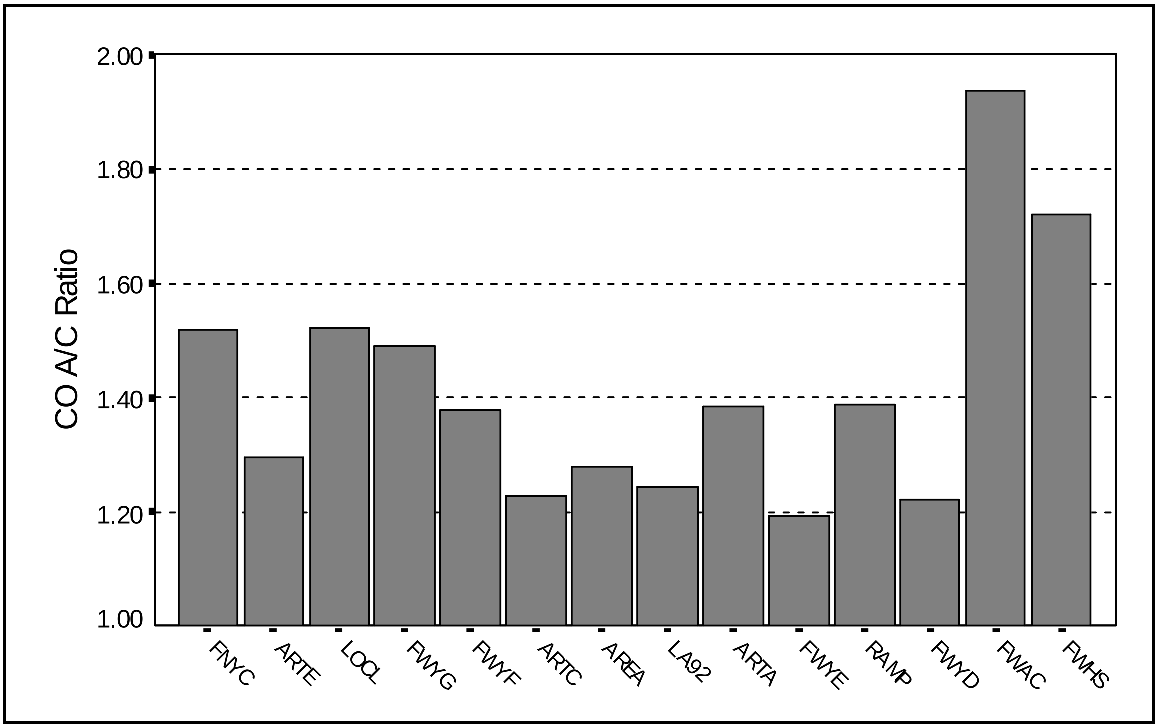

Figure 5 - Fuel Ratio by Vehicle Class

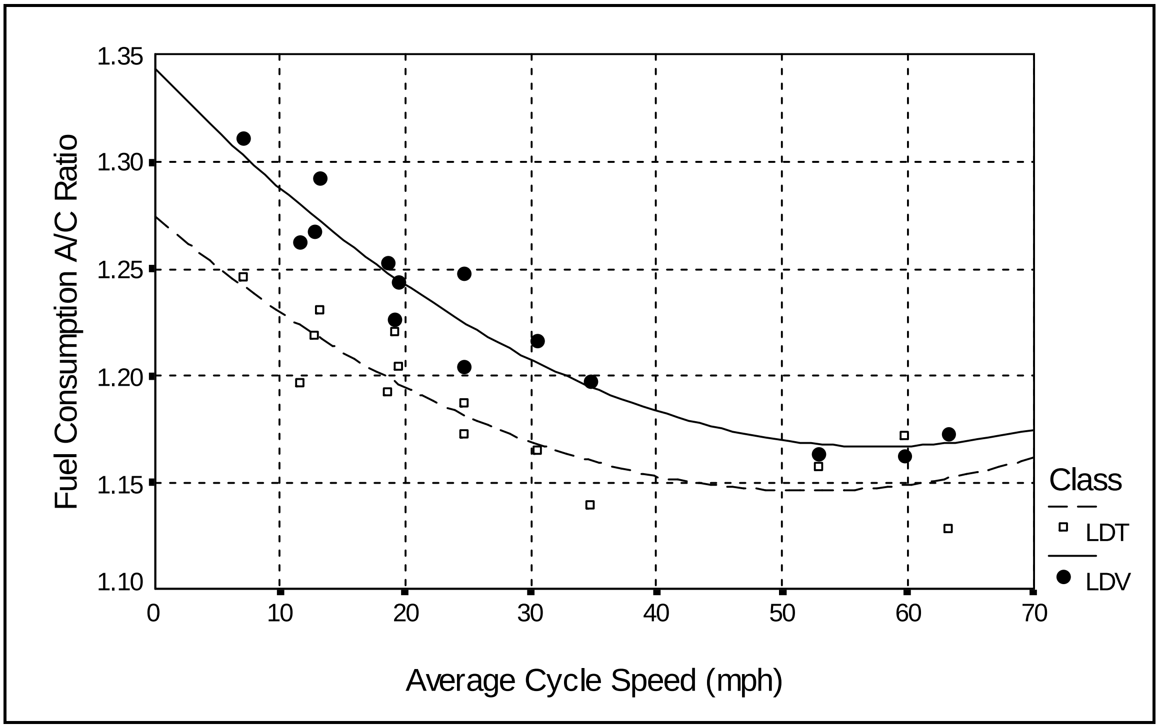

Figure 6 - NOx Ratio by Vehicle Class

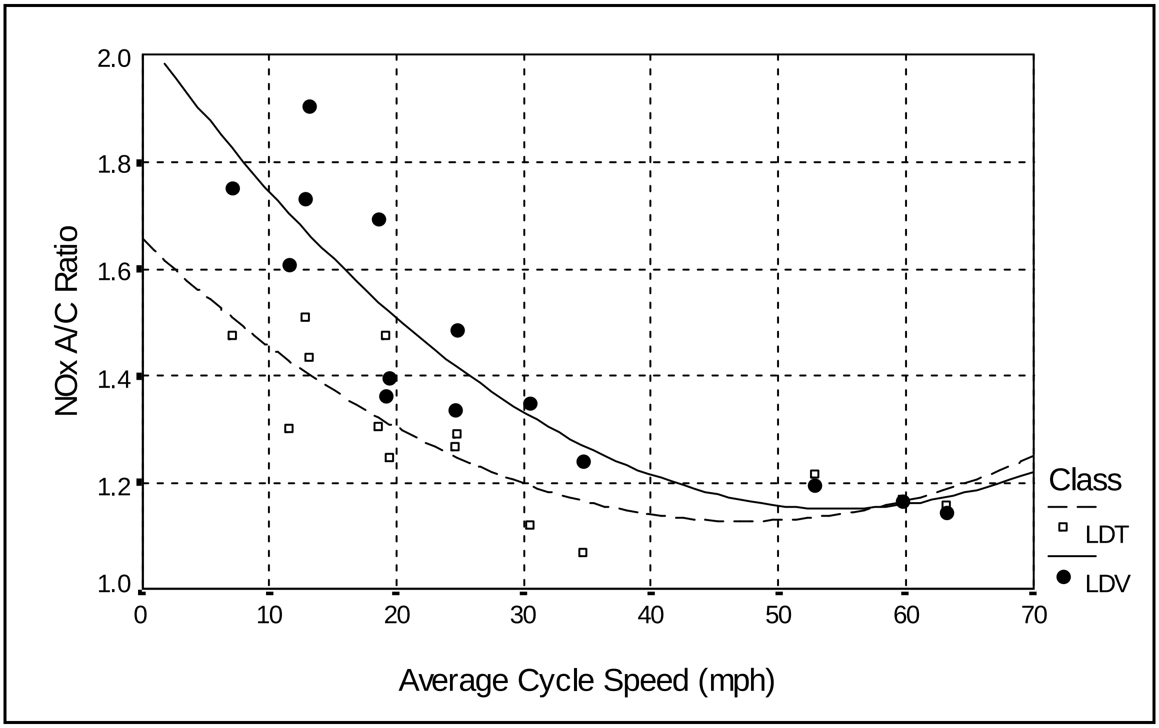

Figure 7 - Normal Emitter NMHC Ratio by Vehicle Class

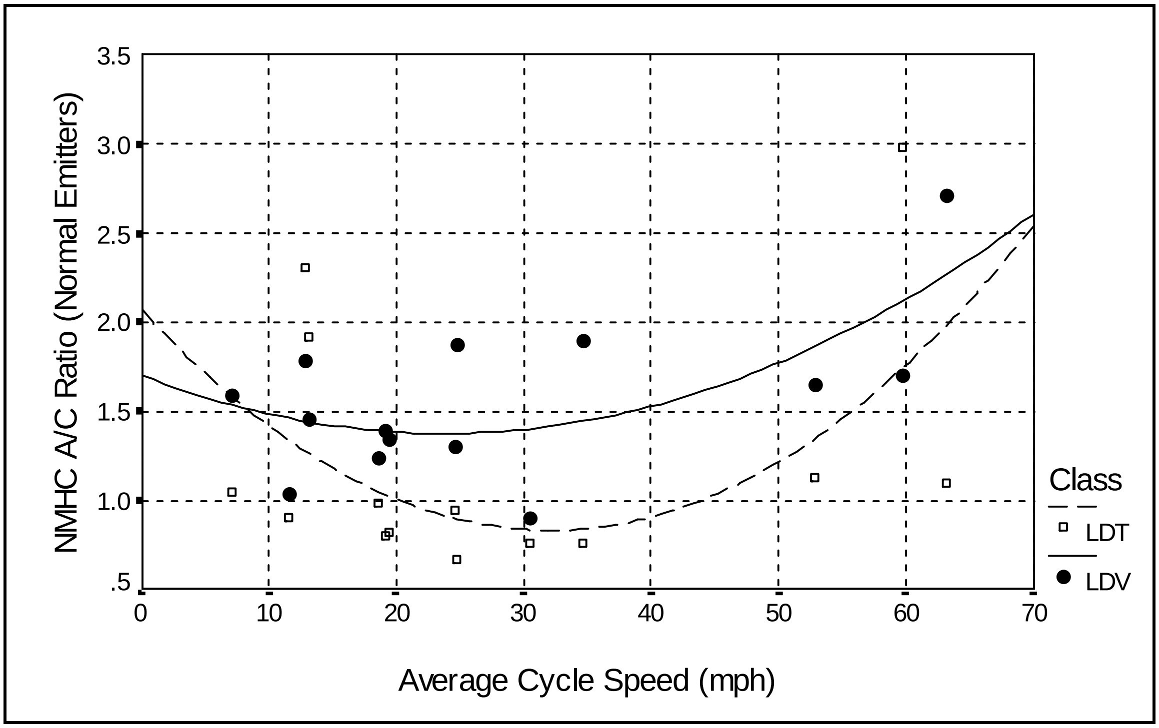

Figure 8 - High Emitter NMHC Ratio by Vehicle Class

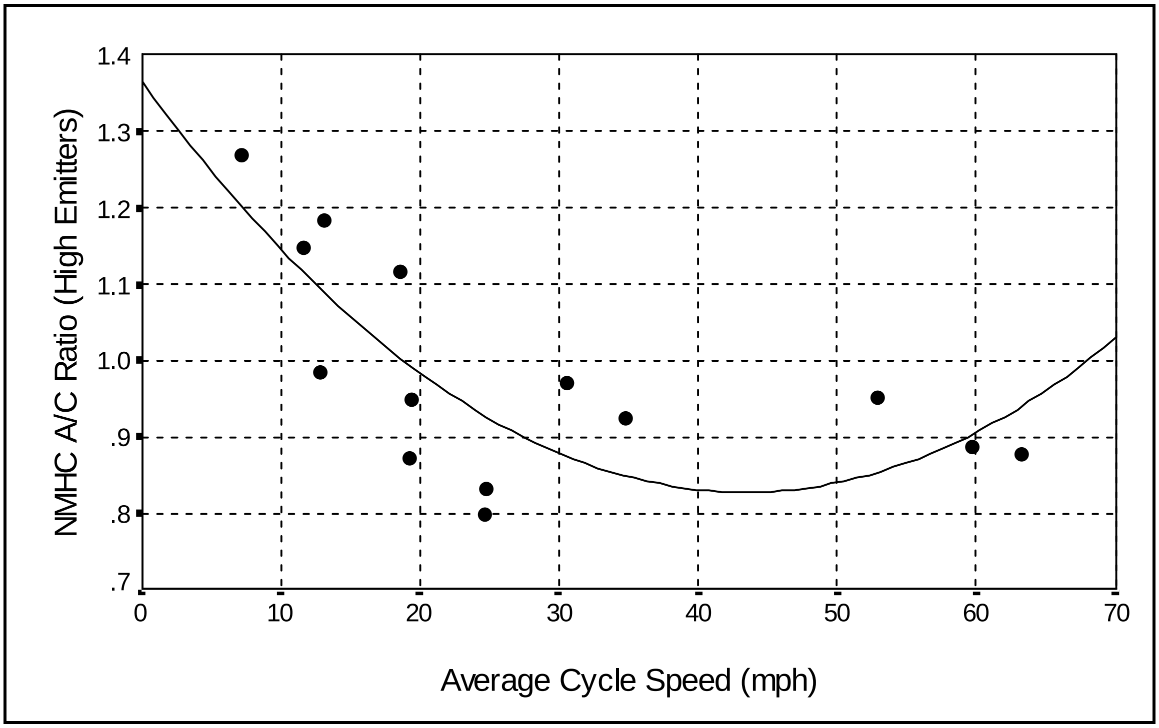

Figure 9 - Normal Emitter CO Ratio by Vehicle Class

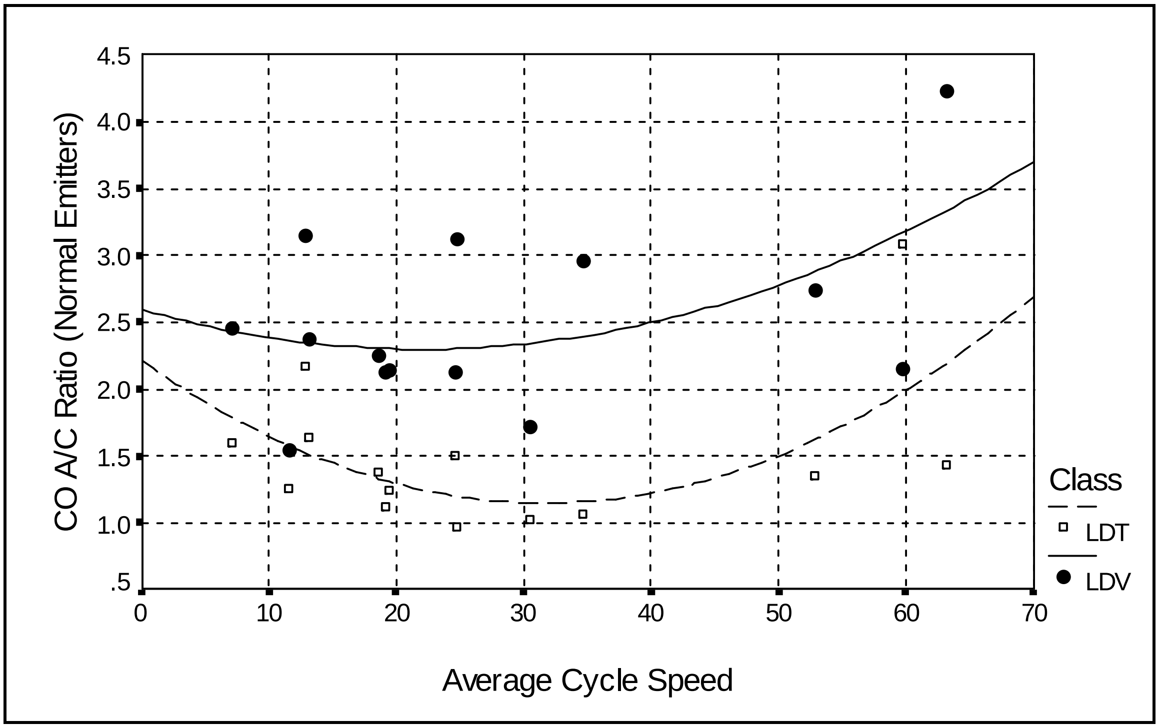

Figure 10 - High Emitter CO Ratio for All Classes