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Comparison of Start Emissions in the LA92 and ST01 Test Cycles

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1.0 Introduction

As part of the MOBILE inventory model revision, an effort has been undertaken to model separately start emissions occurring at the beginning of a trip. A special start driving cycle, described below, has been developed for the purpose of measuring this portion of emissions in laboratory testing. However, sufficient data from such tests is not available for use in MOBILE at this time. The Federal Test Procedure (FTP) and its California replacement the LA92, also described below, do include engine start, but use different driving patterns than the special start driving cycle.

This document reports on a comparison of start emissions for two test cycles using data from a sample of five vehicles tested at the EPA National Vehicle and Fuel Emissions Laboratory in Ann Arbor, Michigan. The purpose of the analysis is to determine if, during the start portion of the cycles, there is a significant difference between the cycles in their excess emissions attributable to a cold start condition.

2.0 Vehicle Sample and Testing

The two cycles used in this study were developed recently to serve the needs of revised emissions testing. The 258-second "ST01" cycle was developed as part of EPA's Revised FTP project. It is the first 258 seconds of a longer cycle known as the SC03. For more information about the FTP study and the development of the SC03 driving cycle, see the EPA web site (http://www.epa.gov/otaq/sftp.htm). The ST01 is designed to simulate typical driving during the beginning of a trip and is comprised of observed speed segments of real driving collected as part of that project. The "LA92" cycle (also called the Unified Cycle) was created by the California Air Resources Board to replace the FTP cycle for vehicle emission certification in California. More information about the Unified cyclecan be found on the California Air Resources Board web site (http://www.arb.ca.gov/research/resnotes/notes/96-11.htm). The LA92 also is constructed from segments of actual driving, recorded in the Los Angeles area, and includes elements of driving that are more "aggressive" than any found on the FTP. While the full LA92 cycle lasts 1,436 seconds, only the first 298 seconds are considered in this study. The first 298 seconds of the LA92 matches the elapsed time of the ST01 cycle plus the time needed for the vehicle to return to idle. Figure 1 displays the speed traces for the two cycles. The statistics for these cycles, compared to the first 505 seconds of the LA4 cycle, are shown in Table 5.

Determining when the cold-start portion of a trip ends is not a trivial problem. A typical pattern of modal emissions for identical driving under cold-start and (warm) no-start driving is depicted in Figure 2. In the absence of test variation, the two graphs converge at a specific time which can be defined as the end of the cold start portion. In practice, this point of convergence is not obvious because of random fluctuations from one test to another. However, in the current study if it is assumed that the cold-start and no-start emissions eventually converge within the first 258 seconds, then knowledge of the exact time of that convergence is not needed in order to compute relative emissions from the two operating modes. When the difference between the cold and no-start emissions on a given cycle is calculated, the post-convergence values cancel.

Using this assumption, the primary null hypothesis can be stated as follows: the average difference between cold-start and no-start emissions is the same for the ST01 and LA92 cycles. The average differences are shown graphically in Figure 4. In the current experiment, each of five vehicles was driven over the two cycles in both a cold-start and warm no-start condition, a total of twenty tests. (A third "hot-start" test also was performed in which the warmed-up vehicle started from engine off mode.) Duplicate tests were not done. From these tests, a simple paired difference test can be constructed by first computing the excess of cold-start over no-start emissions for each vehicle on each cycle, and then differencing these values by vehicle.

Table 1 gives characteristics of the five vehicles employed in the study. Figure 3 shows the second-by-second HC emissions for one of these vehicles on the first 298 seconds of the LA92 cycle in the cold- and no-start conditions. Also shown are the cumulative emissions for the two tests. The difference in cumulative emissions at 258 seconds (the end of the shorter ST01 test) becomes the basic data measurement on which the cycle comparison is based. Table 2 lists all the cumulative values for CO, HC, and NOx; excess cold-start emissions by start condition and resulting cycle differences appear in Table 3.

3.0 Results and Conclusions

Table 3 shows final t-test results for the hypotheses that the average difference between cold-start and no-start emissions is the same for the ST01 and LA92 cycles. These small sample tests are non-significant for all three pollutants. In other words, they support the idea that, on average, excess emissions from cold-start operation are no different for the LA92 cycle than for the ST01 cycle. The variability of the emission results, especially for NOx emissions, was very high. Further analysis may be warranted to investigate the reasons for this variability or to increase the sample size.

It should be noted, of course, that these results do not conclusively prove that excess emissions for a cold start are the same on ST01 as for any other driving pattern. Imputing that conclusion to other cycles (such as the FTP cycle) should be done with caution. Moreover, because the number of vehicles tested was small, the power of the t-test to detect a difference between cycles is limited.

Nevertheless, this study supports the concept that the increment in emissions caused by engine start is reasonably independent of the underlying driving cycle. For the MOBILE6 model, the emissions caused by engine start will be extracted from existing FTP and LA92 emission testing data. It is proposed, for purposes of modeling with MOBILE6, that the emissions from engine start will be assumed to be the same, regardless of the driving which occurs after engine start. Other factors, such as temperature, fuel composition and soak time since the last engine running will still be used to affect the emissions from engine start for particular, user specified scenarios.

There were no specific comments or criticisms of the conclusions found in this report during the development of the MOBILE6 model.

Table 1
Test Vehicle Sample Characteristics

VEHICLE	MODEL YEAR	MAKE	MODEL
5174	91	CHEVROLET	CORSICA
5177	94	FORD	THUNDERBIRD
5181	94	OLDSMOBILE	ACHIEVA
5182	94	BUICK	ROADSTER
5183	94	SATURN	SATURN

VEHICLE	VIN	ENGINE FAMILY	TRANSMISSION
5174	1G1LT53G3ME142337	M1G2.2V5JFG3	AUTOMATIC
5177	1FALP624ORH110885	RFM3.8V8GAEA	AUTOMATIC
5181	1G3NL15D7RM029502	R1G2.3VHGFEA	AUTOMATIC
5182	1G4BN52P3RR420339	R1G5.7V8GAEE	AUTOMATIC
5183	1G8ZJ5574RZ301364	R4G1.9VHGBEA	MANUAL

VEHICLE	CID	DRIVE TRAIN	CATALYST	CYLINDERS	FUEL SYS
5174	134	FWD	3-WAY	4	TBI
5177	231	RWD	3-WAY	6	PFI
5181	139	FWD	3-WAY	6	PFI
5182	350	RWD	3-WAY	4	PFI
5183	145	FWD	3-WAY	8	PFI

Table 2
258 Second Cumulative Emissions
(total emissions in grams)

Vehicle	Cycle	No Engine Start			Cold Engine Start		
		CO	THC	NOx	CO	THC	NOx
5174	LA92	5.74	0.42	0.49	24.75	1.96	1.16
	ST01	6.17	0.48	0.67	23.49	2.25	2.41
5177	LA92	9.22	0.36	0.76	19.32	1.92	1.87
	ST01	15.76	0.34	0.48	28.05	2.08	0.51
5181	LA92	3.58	0.05	0.26	12.76	1.31	0.88
	ST01	5.3	0.05	0.24	14.21	1.26	0.97
5182	LA92	0.39	0.02	0.02	9.09	1.13	0.29
	ST01	0.78	0.02	0.09	12.92	1.2	0.53
5183	LA92	5.91	0.21	0.12	19.25	1.71	0.49
	ST01	4.95	0.11	0.13	17.59	1.39	0.19

Table 3
Excess of Cold-Start Over No-Start Emissions
By Vehicle and Cycle with Paired Difference (grams)

Vehicle	Cycle	CO	THC	NOx
5174	LA92	19.01	1.54	0.67
	ST01	17.32	1.76	1.74
	Difference	1.69	-0.22	-1.07
5177	LA92	10.1	1.56	1.1
	ST01	12.29	1.75	0.04
	Difference	-2.19	-0.19	1.07
5181	LA92	9.18	1.26	0.62
	ST01	8.91	1.21	0.73
	Difference	0.27	0.06	-0.11
5182	LA92	8.7	1.11	0.26
	ST01	12.14	1.18	0.44
	Difference	-3.44	-0.07	-0.17
5183	LA92	13.34	1.5	0.37
	ST01	12.64	1.28	0.06
	Difference	0.7	0.22	0.31

Table 4
Paired Difference T-Tests for Differences in Table 3

Statistics	CO	THC	NOx
Minimum (grams)	-3.44	-0.22	-1.07
Maximum (grams)	1.69	0.22	1.07
Mean Difference (grams)	-0.59	-0.04	0.01
Std Deviation (grams)	2.14	0.18	0.78
Standard Error	0.96	0.08	0.35
T	-0.62	-0.49	0.02
PROB > T	0.57	0.65	0.99

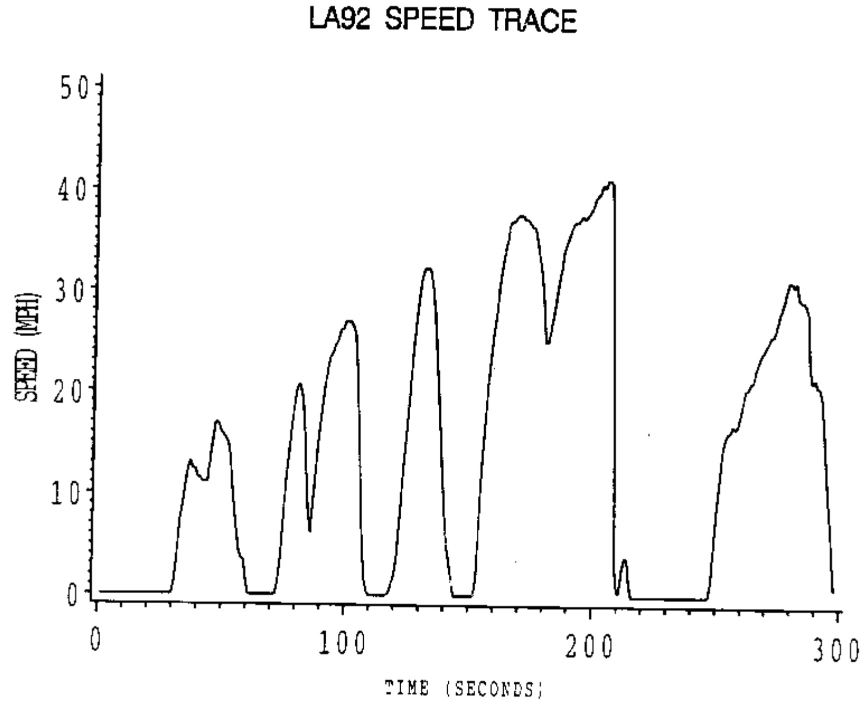
Table 5 **Driving Cycle Statistics**				
Cycle	LA92	ST01	LA4 Bag 1	Units
Time	298	258	505	seconds
Distance	1.2	1.4	3.6	miles
Average Speed	13.6	19.4	25.6	miles per hour
Maximum Speed	41.1	40.1	56.7	miles per hour
Maximum Acceleration	5.8	5.1	3.3	mph/second
Average Power*	19.5	21.4	19.6	$(\text{mph})^2$

*This metric represents the mean specific power of the entire driving cycle. Specific power was calculated for each second from the following equation:

$$P_t = \begin{cases} S_t^2 - S_{t-1}^2 & \text{, if } S_t > S_{t-1} \\ 0 & \text{, if } S_t \leq S_{t-1} \end{cases}$$

where S_t and S_{t-1} are the vehicle speeds at times t and $t\text{-}1$, respectively. The average power metric reported was calculated from the mean of the specific power calculated for each second, including zeros.

Figure 1


LA92 SPEED TRACE
SPEED (MPH)
0
10
20
30
40
50
0
100
200
300
TIME (SECONDS)

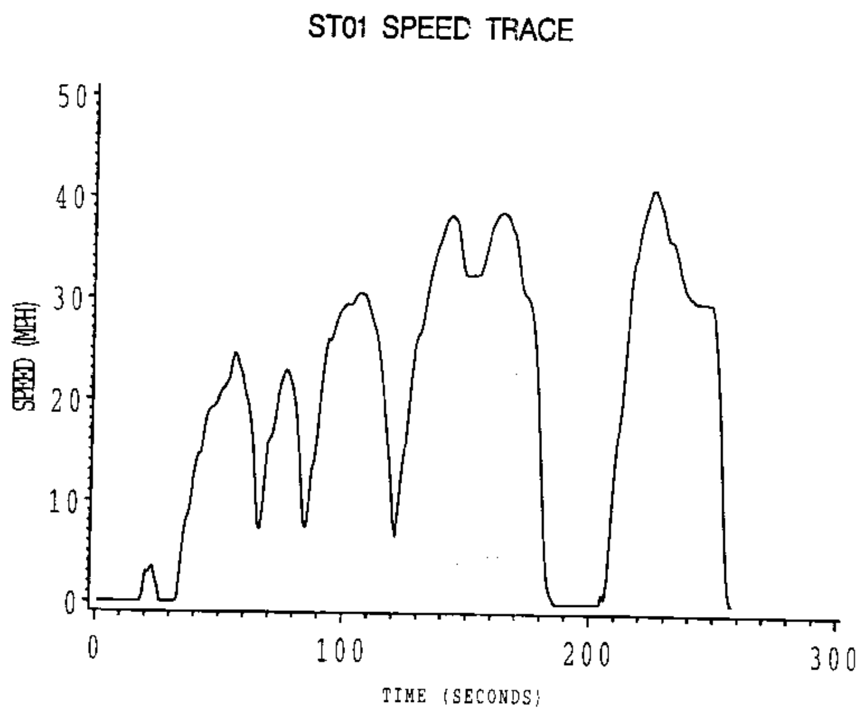

ST01 SPEED TRACE
SPEED (MPH)
0
10
20
30
40
50
0
100
200
300
TIME (SECONDS)

Figure 2

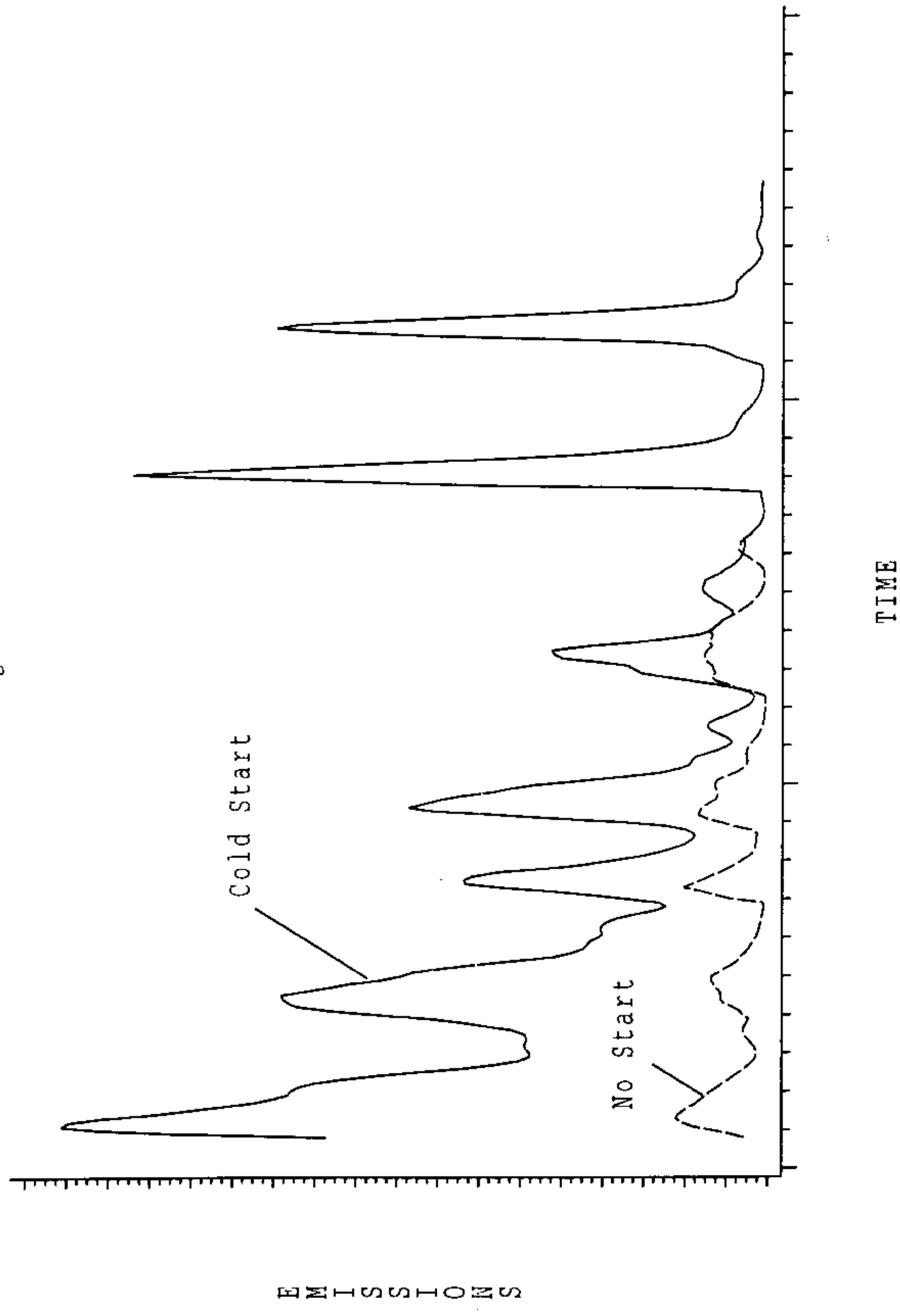


Figure 3

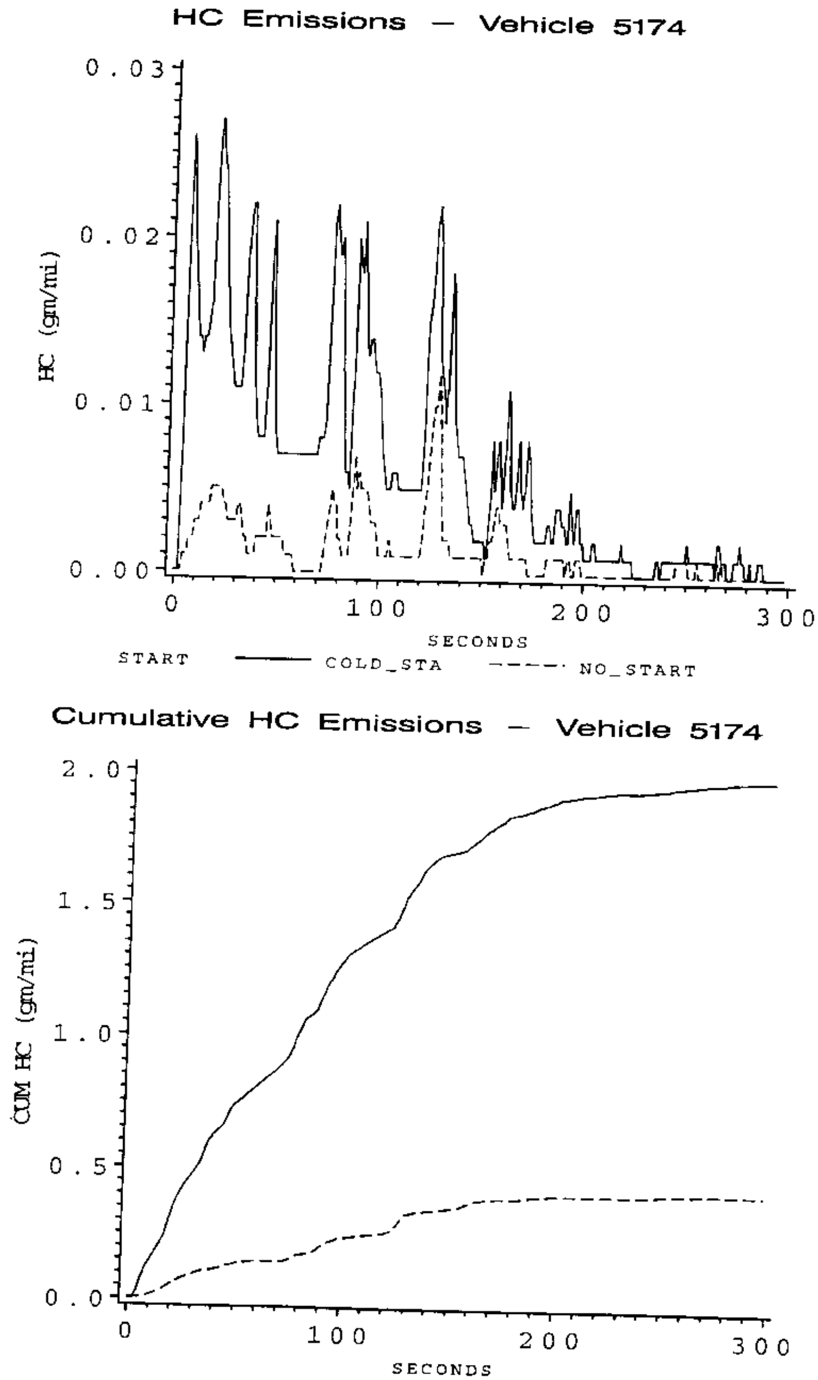
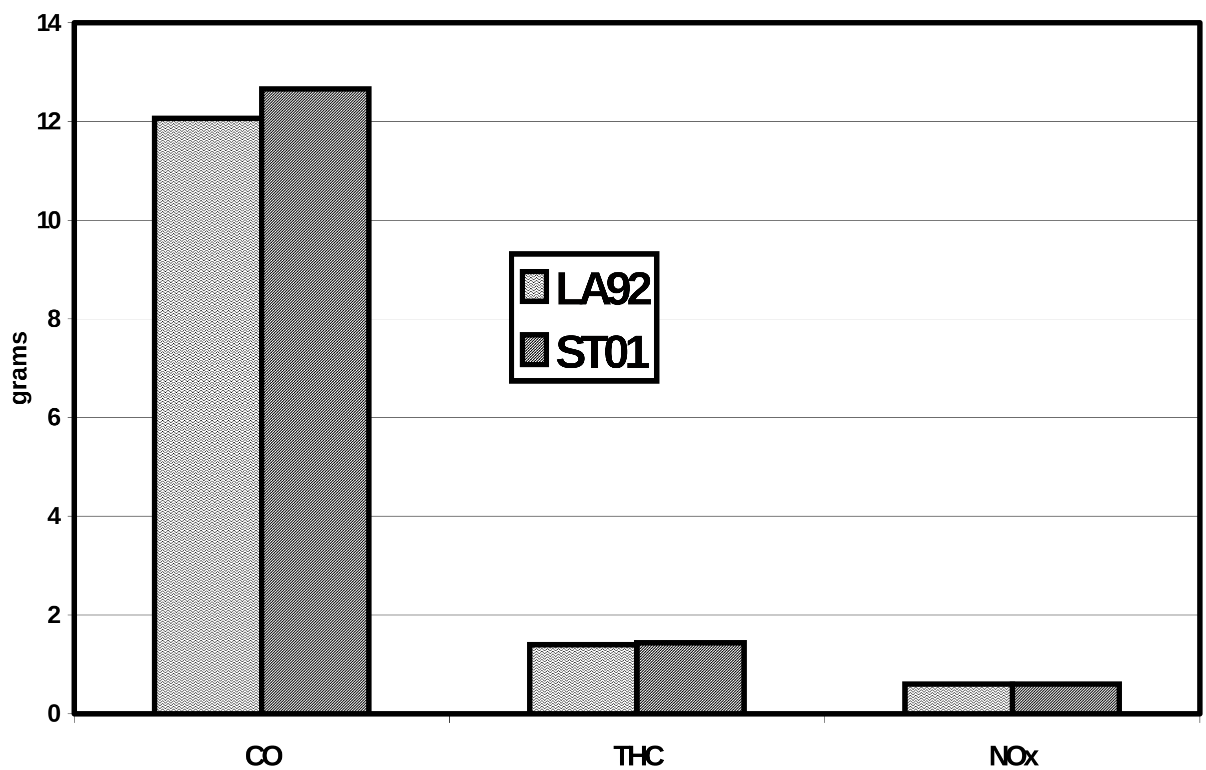

HC Emissions — Vehicle 5174
HC (gm/mi)
0.00
0.01
0.02
0.03
0
100
200
300
SECONDS
START
COLD_STA
NO_START
Cumulative HC Emissions — Vehicle 5174
CUM HC (gm/mi)
0.0
0.5
1.0
1.5
2.0
0
100
200
300
SECONDS

Figure 4
Average of the Emission Differences Due to Engine Starts



Appendix A

Test Plan
Evaluation of the Effects of Driving Cycles on Cold Start Emissions

BACKGROUND

A theory has been presented that cold start emissions are independent of specific driving circles. In other words, no matter what driving occurs immediately after a vehicle is started the emissions over the time it takes for the engine to warm up are the same.

PURPOSE

The purpose of this testing is to gain some insight into whether or not the cold start emissions of a vehicle are independent of driving patterns. This is a preliminary investigation which could result in further testing.

RECRUITMENT

Five vehicles shall be selected to receive a series of cold start tests after the normal Emission Factor Indolene test sequence. Because the data are needed quickly, the next five available EF vehicles shall be used. The vehicles selected shall be 'normal' emitting. No high emitting vehicles are to be included in this sample. If it is determined, after testing begins, that a vehicle is a high emitter it shall be removed from this program and another vehicle selected in its place.

TESTING

This testing shall be performed after the normal EF sequence on Indolene. The sequence shall be as shown on the attached flowchart. The cycles to be used for this testing will be the ST01 (first 258 seconds of the SC03 cycle) and the first 298 seconds of the LA92 (Unified Cycle). Each of these cycles will be performed modally both as a cold start, hot start, and running start test.

TEST SEQUENCE

The test sequence shall begin no sooner than four hours after the Indolene testing has been completed. The sequence shall begin by draining the fuel and filling the tank to 40%, by volume, with Indolene test fuel. An LA4 prep cycle shall be driven and vehicle soaked for a minimum of 12 hours. An effort shall be made to soak the vehicle approximately the same length of time after each prep, before each cold start. The vehicle will then receive a cold start

ST01 with second by second dilute modal emission measurements and a bag sample. An unmeasured hot LA4 will then be driven followed by a 10 minute soak and a hot start ST01 and a running ST01 after the hot start test (back to back ST01 cycles).

No sooner than four hours later, an LA4 prep cycle shall be driven and the vehicle soaked for a minimum of 12 hours. The vehicle will then receive a cold start with second by second dilute modal emission measurements and a bag sample of the first 298 seconds of the LA92 cycle. An unmeasured hot LA4 will then be driven, followed by a 10 minute soak and a hot start 298 second test and a running 298 second test (back to back 298 second tests).

The order of testing shall be alternated for each vehicle. The first vehicle will have the ST01 sequence first, the second vehicle will have the 298 second sequence first. The third vehicle, the ST01 first, and so on.

DATA COLLECTION

All data collected on these cycles will be second by second dilute modal and be simultaneously collected in a bag.

Appendix

Response to Comments

<u>AIR Comments</u>:

Air Improvement Resource, Inc., commented on June 4, 1997 on this report:

The major comment or question is why these two particular start cycles were chosen to determine the sensitivity of emissions to start cycle? Examination of the speed-time traces for the two test cycles in Figure 1 shows that they appear to be very similar with respect to average speed, acceleration, and the placement of the modal patterns. (No statistics on the cycles were presented in the report.) The vehicles tested experienced similar HC and CO for both cycles, but as was pointed out in the report, NOx emissions were quite different on both cycles, and there appeared to be no clear trends (one cycle was not necessarily higher than another for NOx). So, if the start cycles are very similar, then one would not expect to see much difference in the cold start increment. My recommendation would be to provide a comparison of the two cycles, in terms of average speed, minimum and maximum acceleration, power, etc. so that reviewers will have a better idea how different these cycles are.

The ST01 cycle was developed specifically to represent the observed driving behavior following an engine start using data from instrumented vehicles. The LA92 is more representative of driving cycles (like the LA4 cycle used in the Federal Test Procedure, FTP) which do not explicitly attempt to account for the effect of engine starts on the first portion of driving behavior. The hypothesis being tested is to determine if, within the relatively small differences between the two cycles, there is a disproportionate difference in engine start emissions. If a large difference was observed, this would suggest that the choice of driving cycle would be critical to estimating engine start emissions. The small differences we observed, suggest that a fairly accurate estimate of engine start emissions can be obtained with any reasonably constructed inventory driving cycle. The statistics related to the driving cycles you requested have been added to the report in Table 5.

The report states that EPA will be developing cold start emissions from data collected on the LA-4 and the LA92. The LA92 was tested in this start emissions test program, why wasn't the LA-4? The LA-4 start cycle (or first 250 seconds) is very different from these other two cycles (the second mode of the LA-4 exceeds 50 mph). I think that this is interesting work, but I would be much more comfortable with the conclusion (that the start increment is independent of the cycle) had EPA selected three or four start cycles that represented a fuller range of start driving behavior.

At the time of this study, it was not clear that the LA4 would be used to estimate engine start emissions, since the ST01 was developed specifically to estimate emissions from driving behavior following an engine start. The LA92 was a candidate cycle for estimating baseline emission rates from vehicles, as a substitute for the LA4 driving cycle. The initial focus of this study was to determine if it would be necessary to measure an ST01 driving cycle in addition to an LA92 driving cycle for each vehicle in order to appropriately estimate the effects of an engine start. The scope of the conclusions of this study have been expanded to include the idea that the LA4 would be used to determine engine start emissions, instead of the LA92.

> *The test plan listed in the Appendix shows that EPA conducted some "running start" tests, and yet the results of these were not summarized in report. Does EPA plan to provide these at a later date?*

The emissions labeled "No Engine Start" in Table 2 are the "running start" test results for these vehicles. It is the difference between the emissions measured which include an engine start and those that do not which are analyzed in this report.

Once the LA4 cycle was chosen to represent driving behavior after an engine start, a "hot running" 505 (HR505) measurement was added to a vehicle sample that was collected for use in MOBILE6. This measurement was performed on a fully warmed engine and did not include an engine start. The HR505 results could then be directly compared with Bag 1 and Bag 3 of the FTP test procedure results (which all use the first 505 seconds of the LA4 driving cycle) to determine the effects of engine starts on emissions. The results of this study are summarized in the report, "The Determination of Hot Running Emissions From FTP Bag Emissions," (M6.STE.002) EPA-420-P-99-014. The data is included in the full Mobile Source Observation Database (MSOD) which is available from EPA on request.

Review of "Comparison of Start Emissions in the LA92 and ST101 Test Cycles"

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Center for Statistical Consultation and Research
The University of Michigan
May 6, 1998

This document consists of a review, divided into two sections, of the report by US EPA Assessment and Modeling Division prepared by Enns and Brzezinski (1997). Section 1, contains a brief synopsis of the report;. Section 2, is comprised of several recommendations for improving the statistical methodology of the report.

In general, while the statistical tests presented in Enns and Brzezinski (1997) are sound and appropriate, we suggest that:

(1) non-parametric tests and tests for normality should also be presented;
(2) that additional diagnostic tests be performed; and
(3) that several additional summary statistics be calculated to aid in the interpretation of the results.

We also suggest methods that could be used to analyze more complex experimental designs for related future research.

1 Synopsis of the Report

The purpose of Enns and Brzezinski was to test the hypothesis that start up emissions are independent of starting driving cycle.

The experiment conducted to test this hypothesis has the form of a classical cross-over design. (See Jones and Kenward [1989], Ratkowsky, Evans, and Alldredge[1993], and the references cited in these works.) To describe the design in a little more generality than was done by Enns and Brzezinski:

(1) let A and B represent two test cycles that are to be compared;,
(2) let C be a third test cycle used to warm the vehicle up; and
(3) let W_1,W_2 and W_3 be three waiting periods.

In Enns and Brzezinski A was the STO1 cycle, B was the LA92 cycle, C was the LA4 cycle, W_1 waiting periods was a 12 hours wait, W_2 was 4 hour wait, and W_3 was a 10 minute wait.

In the experiment described by Enns and Brzezinski, roughly half the cars are put through the sequence:

$$W_1AW_2CW_3AA \quad W_1BW_2CW_3BB \tag{1}$$

and the other half of the vehicles are put through the sequence

$$W_1BW_2CW_3BB \quad W_1AW_2CW_3AA. \tag{2}$$

Although this design looks complicated, it can be considereedto be a simple 2 x 2 cross-over design, where, abusing our notation slightly, (1) can be calledAB and (2) can be called BA. (There is a large body of literature on cross-over designs and the issues involved in their analysis.) The standard analysis for this type of design typically involves tests for treatment (A vs.B), period(1 vs. 2), sequence(AB vs. BA), and two-way interactions. In a 2 x 2 cross-over trial, only three degrees of freedom are available for performing tests, therefore, interpretation of significant results from some tests may be ambiguous.

In biological experiments, tests of carry over effects from the first period to the second period are often of interest. In the study of Enns and Brzezinski, it is unlikely that carryover effects will be present, and period effects are likely to be small or nonexistent. However, given the cross-over design, tests of such effects should be performed as a precautionary measure.

More formally, cars put through the sequence (1) will be called Order 1 cars and cars put through the sequence (2)) will be called Order 2 cars. A is measured in the first period for Order 1 cars and the second period for Order 2 cars. Similarly, B is measured in the first period for Order 2 cars and the second period for Order 1 cars.

Continuous time measurements of the emission of CO, HC, and NOx where taken at the first, second, and third runs of cycle A and the first, second, and third of runs of cycle B These measurements will be designated as the cold start, warm start, and nostart measurements of cycles A and B respectively. Enns and Brzezinski analyze only the cold start and nostart measurements and (correctly in our view) perform a separate analysis for each emittant.

Let X denote an arbitrary emittant. Interest focus on the measurement of the contrast:

$$C_{A,B} = (X(cold,A) - X(nostart,A)) - (X(cold,B) - X(nostart,B)). \tag{3}$$

In particular,

$$C_A = X(cold,A) - X(nostart,A) \tag{4}$$

represents the emissions of X in cycle A that can be attributed to the cold start and

$$C_B = X(cold,B) - X((nostart,B) \qquad (5)$$

represents the emissions of X in cycle B that can be attributed to the cold start, and $C_{A,B}$ represents the differences in such emissions between cycles Table 3 in Enns and Brzezinski shows that C_A and C_B are both positive for all cars and emittants cycles tested. Enns and Brzezinski test the null hypothesis that $C_{A,B}$ is zero by using a two sided one sample T-test. This is correct, although the bottom row in Table 4 is labeled as though it contained p-values for a one sided test.

In order to insure the validity of the T-test described in the previous paragraph, we should verify that the contrasts C_A and C_B do not depend on the order in which the measurements were made. To make this explicit, we may label four new contrasts as follows:

$$C_{A,1} = X(cold,A,1) - X(nostart,A,1)$$
$$C_{A,2} = X(cold,A,2) - X(nostart,A,2)$$
$$C_{B,1} = X(cold,B,1) - X(nostart,B,1)$$
$$C_{B,2} = X(cold,B,2) - X(nostart,B,2) \qquad (6)$$

Several hypothesis tests can be performed to investigate order effects among the contrasts in (6). These include tests of the hypothesis:

$$C_{B,2} - C_{A,1} = C_{B,1} - C_{A,2} \qquad (7)$$
$$C_{B,2} + C_{A,1} = C_{A,2} + C_{B,1} \qquad (8)$$
$$C_{A,1} = C_{A,2} \qquad (9)$$
$$C_{B,2} = C_{B,1} \qquad (10)$$

The first of these hypothesis tests, (7), is known, in terminology of cross-over designs, as a test for a period effect; the second, (8), is a test for a period by treatment interaction; (9) and (10) are tests which can be used to identify the source of unwanted order effects. In general, all of the hypothesis (7-10) can be tested using two sample T-tests or two sample non-parametric tests. To see this, note that all of the left hand sides of the equations (7-10) can be computed from contrasts measured on Order 1 cars and the right hand sides of the equations (7-10) can be measured from contrasts on Order 2 cars. If any of the above tests are significant, it is evidence for an order dependence in the measurement of C_A and/or C_B. If such a dependence is found, it might be cured by lengthening the soak time, W_1.

Alternatively, one might need to identify and neutralize a confounding factor that is correlated with period. For example, it might be discovered that first period experiments tended to be carried out in the morning and second period experiments tended to occur in the afternoon. If weather conditions tended to differ between morning and afternoon, this could, in theory,
affect emissions measurements at these times.

One way to analyze the above experiment is to use a repeated measures analysis of variance, as in SAS PROC REG (SAS, 1989). This ANOVA would include two within subjects factors, START(cold, no) and CYCLE(A,B), and a between subjects (or grouping) factor ORDER(1,2), 1 for the order in (1) and 2 for the order in (2). (A subject in this experiment is a specific car). In the repeated measures framework, the test of the null hypothesis that $C_{A,B} = 0$ would be equivalent to the test of the START by CYCLE interaction, the period effect (7) would be tested by checking the START by CYCLE by ORDER interaction, and the period by treatment effect (8)would be tested by checking the START by ORDER interaction. All of the tests for the above repeated measures ANOVA are equivalent to one or two sample T-tests. The repeated measures framework can, however, accommodate designs which cannot be analyzed by simple T-tests. This would occur if, additional grouping factors were added to the design to test for effects caused by characteristics of the vehicles being tested, i.e. high, medium, or low emitters, or if additional levels of the START factor (e.g. warm start) were added.

2 Recommendations

We suggest that the T-tests presented in Table 4 be supplemented with non-parametric Wilcoxon signed rank tests and sign tests . As is well know, T-tests assume that the contrast in (3) is normally distributed. Formal tests for normality should be performed and normal probability plots should be consulted to evaluate the accuracy of this assumption. With the extremely small sample sizes encountered in the report, however, substantial doubt regarding the assumption of normality is likely to remain after all such tests have been completed and all of such plots observed. Under these conditions it is best to guard oneself against the possibility of error by performing parallel analyses which have lower power but fewer assumptions. Although less powerful than the Wilcoxon signed rank test, we suggest that the sign test be presented, in addition to the Wilcoxon Signed Rank test, because exact small sample p-values are generally available for the sign test, even in the presence of ties. Both non-parametric tests and tests for normality are readily available in PROC UNIVARIATE in SAS (SAS (1990)). Exact p-values for the Wilcoxon signed rank test are available (for example) in the S-PLUS statistics package (Statistical Sciences (1995) unless ties are present in the data.

We suggest that standard errors and confidence intervals be presented for the contrasts in (3), (4), (5), and (6). Confidence intervals are useful, even in the absence of statistically significant results, because they help one assess the strength of the evidence in favor of the null hypothesis.

We further suggest that a standard battery of tests, pertinent to a 2 x 2 cross-over design be performed, as described above. In particular, we suggest that two sample T-tests and non-parametric Kruskal-Wallis tests be computed for testing the hypothesis in (7-10). These tests are available in PROC T-TEST and PROC NPARONEWAY in SAS (1989). The purpose of this analysis is to attempt to identify order related dependencies in the contrasts C_A and $C_{B.}$

We also suggest that additional summary statistics be presented that would help the reader assess the relative magnitudes of the emissions attributable to the cold start compared to emissions caused by normal running of the engine. In particular, we suggest that means and standard errors for statistics of the form

$$\frac{X(cold,A) - X(nostart,A)}{X(nostart,A)} \qquad (11)$$

be computed. Means, standard errors, and T-tests could also be computed for dfference scores of the form

$$\frac{X(cold,A) - X(nostart,A)}{X(nostart,A)} - \frac{X(cold,B) - X(nostart,B)}{X(nostart,B)} . \qquad (12)$$

Finally, we suggest that the analysis of the current experiment include an additional level of the within factor (i.e. a warm start level for the START factor). New experiments of the same type might also include additional grouping factors as described in the previous section. If more complicated designs of this sort are considered, the analysis could make use of the repeated measures facilities of SAS PROC GLM.

References

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EPA Response to the Center for Statistical Consultation and Research Review of Comparison of Start Emissions in the LA92 and ST101 Test Cycles

The reviewers at the Center for Statistical Consultation and Research Review have suggested a series of detailed statistical descriptions of the data to assist readers in assessment of the validity of the report conclusions. Some of these suggestions are addressed in Tables 6 through 10 below. If additional statistical information about the data is required, the data used in this report has been made available along with this report.

Table 6
Statistics for the Engine Start Emissions Increment* by Cycle

CYCLE	Statistic	CO (grams)	THC (grams)	NOx (grams)
LA92	Mean	12.0660	1.3940	.6080
LA92	Std. Deviation	4.2827	.1992	.3267
ST01	Mean	12.6600	1.4360	.6000
ST01	Std. Deviation	3.0077	.2936	.6997

* Cold start emissions measurement minus the no start emissions.

Table 7
Paired Samples Test of the Engine Start Increment

Pollutant*	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
CO (grams)	-.5940	2.1380	.9562	-3.2487	2.0607	-.621	4	.568
THC (grams)	-4.2000E-02	.1819	8.133E-02	-.2678	.1838	-.516	4	.633
NOx (grams)	8.000E-03	.7823	.3499	-.9634	.9794	.023	4	.983

* Cold start emissions measurement minus the no start emissions.

Table 8
Engine Start Emissions
As a Proportion of Emissions Without An Engine Start

Cycle	Pollutant (grams)*	Minimum	Maximum	Mean	Std. Error	Std. Deviation
LA92	CO	1.10	22.31	6.3073	4.0160	8.9800
	THC	3.67	55.50	19.1686	9.9029	22.1436
	NOx	1.37	13.50	4.3592	2.3069	5.1584
ST01	CO	.78	15.56	4.6771	2.7450	6.1380
	THC	3.69	59.00	20.7283	10.2311	22.8775
	NOx	.06	4.89	2.2103	.8856	1.9803

* Cold start emissions measurement minus the no start emissions divided by the no start emissions.

Table 9
Difference in Engine Start Emissions
As a Proportion of Emissions Without An Engine Start
(LA92 versus ST01)

Pollutant	Mean	Std. Deviation	Std. Error Mean
CO (grams)	1.6301	2.8901	1.2925
THC (grams)	-1.5597	2.3395	1.0463
NOx (grams)	2.1488	3.9318	1.7583

* LA92 proportion (cold start emissions measurement minus the no start emissions divided by the no start emissions) minus the ST01 proportion.

Table 10
One Sample Test of Engine Start Emissions
As a Proportion of Emissions Without An Engine Start
(LA92 versus ST01)

Pollutant*	Test Value = 0 t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
CO (grams)	1.261	4	.276	1.6301	-1.9584	5.2187
THC (grams)	-1.491	4	.210	-1.5597	-4.4646	1.3452
NOx (grams)	1.222	4	.289	2.1488	-2.7331	7.0308

* LA92 proportion (cold start emissions measurement minus the no start emissions divided by the no start emissions) minus the ST01 proportion.