Comparison of Start Emissions in the LA92 and ST01 Test Cycles

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Phil Enns
David Brzezinski
U.S. EPA Assessment and Modeling Division

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.

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 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. It 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. This includes 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.

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. 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.

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.

Table 1: Test Vehicle characteristics

VEHICLE	MY	MAKE	MODEL	VIN	ENGINE FAMILY
5174	91	CHEVROLET	CORSICA	1G1LT53G3ME142337	M1G2.2V5JFG3
5177	94	FORD	THUNDERBIRD	1FALP624ORH110885	RFM3.8V8GAEA
5181	94	OLDSMOBILE	ACHIEVA	1G3NL15D7RM029502	R1G2.3VHGFEA
5182	94	BUICK	ROADSTER	1G4BN52P3RR420339	R1G5.7V8GAEE
5183	94	SATURN	SATURN	1G8ZJ5574RZ301364	R4G1.9VHGBEA

VEHICLE	CID	DRIVE TRAIN	CATALYST	CYL	FUEL INJ	TRANS
5174	134	FWD	3-WAY	4	TBI	AUTOMATIC
5177	231	RWD	3-WAY	6	PFI	AUTOMATIC
5181	139	FWD	3-WAY	6	PFI	AUTOMATIC
5182	350	RWD	3-WAY	4	PFI	AUTOMATIC
5183	145	FWD	3-WAY	8	PFI	MANUAL

Table 2

258-SECOND CUMULATIVE EMISSIONS
Total Emissions (grams)

VEHICLE	CYCLE	NO START CO	NO START HC	NO START NOX	COLD START CO	COLD START HC	COLD START 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	5.30	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	1.20	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	HC	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	10.10	1.56	1.10
	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	8.70	1.11	0.26
	ST01	12.14	1.18	0.44
DIFFERENCE		-3.44	-0.07	-0.17
5183	LA92	13.34	1.50	0.37
	ST01	12.64	1.28	0.06
DIFFERENCE		0.70	0.22	0.31

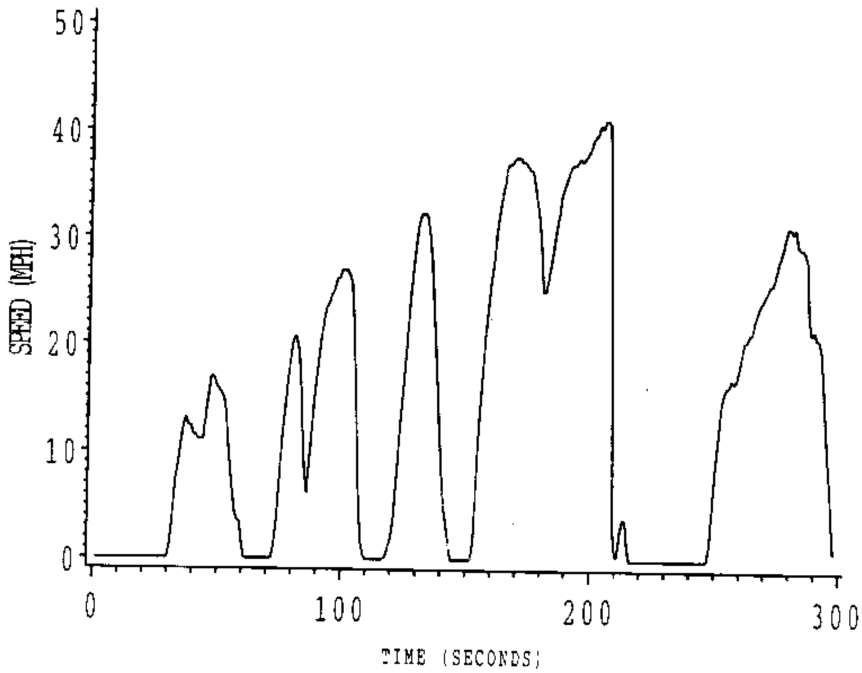
Table 4

PAIRED DIFFERENCE T-TESTS
for DIFFERENCES IN Table 3

	CO	HC	NOX
MINIMUM (grams)	-3.44	-0.22	-1.07
MAXIMUM (grams)	1.69	0.22	1.07
MEAN DIFFERENCE	-0.59	-0.04	0.01
STD DEVIATION	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

Figure 1

LA92 SPEED TRACE



ST01 SPEED TRACE

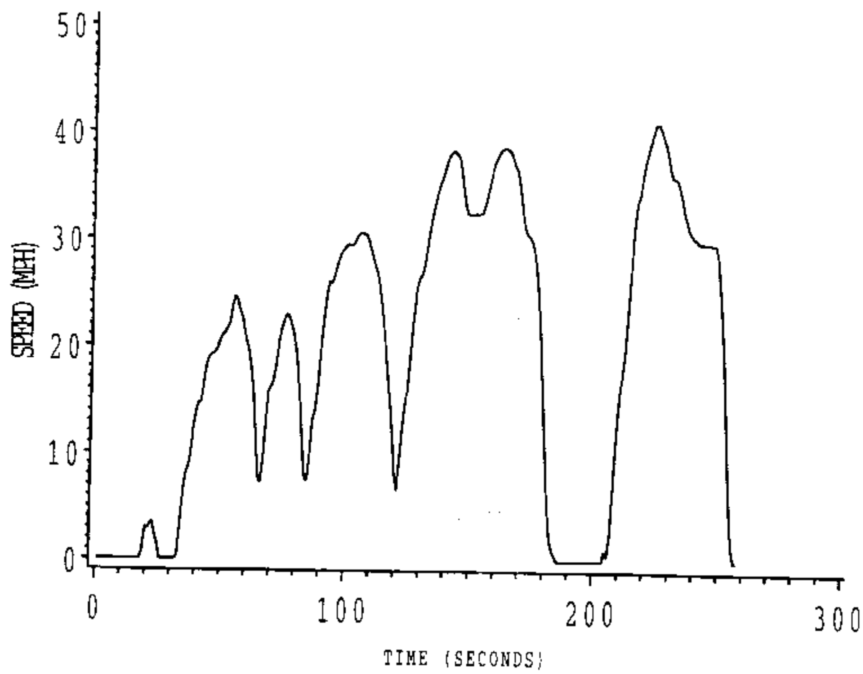


Figure 2

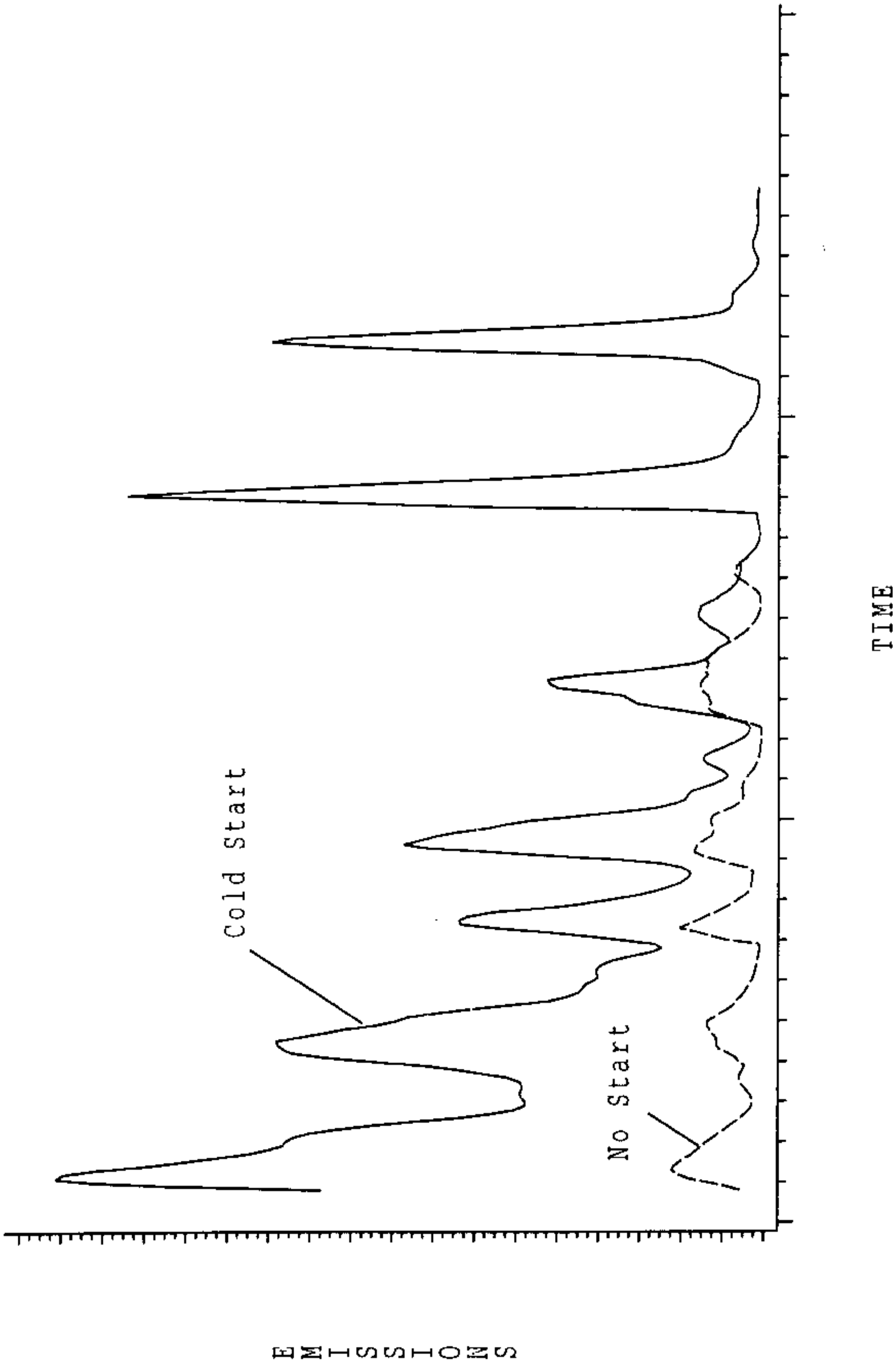
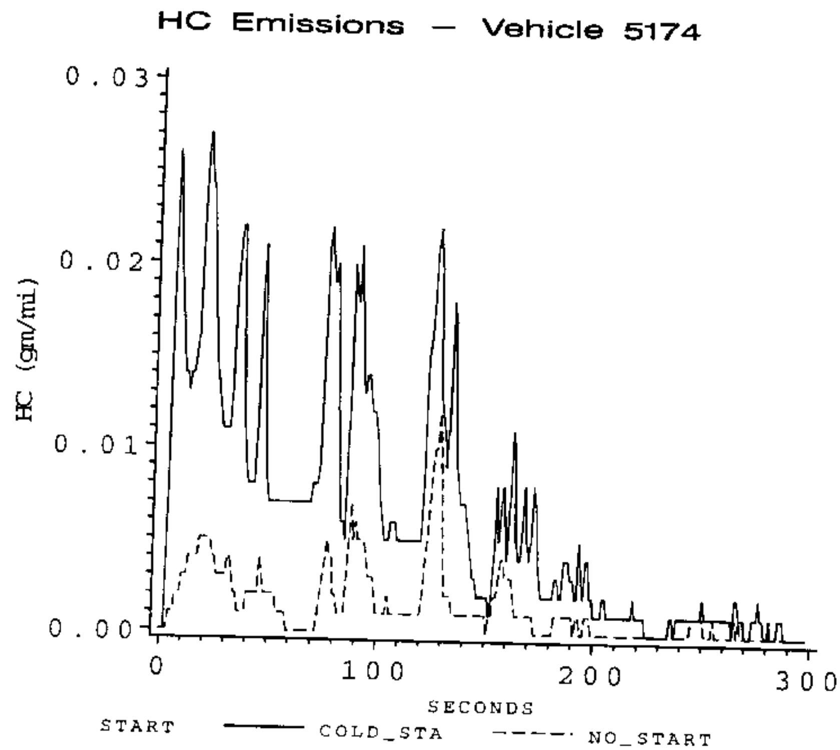
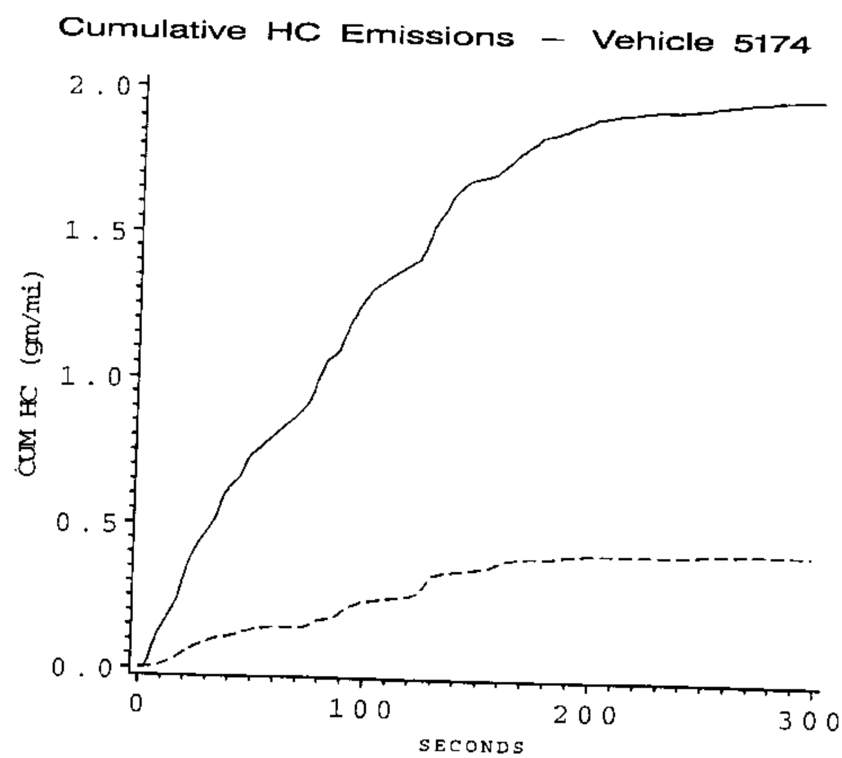


Figure 3


HC Emissions — Vehicle 5174
0.03
0.02
0.01
0.00
HC (gm/mi)
0
100
200
300
SECONDS
START
COLD_STA
NO_START


Cumulative HC Emissions — Vehicle 5174
2.0
1.5
1.0
0.5
0.0
CUM HC (gm/mi)
0
100
200
300
SECONDS

Appendix

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.