Summary and Analysis of Comments on the Notice of Proposed Rulemaking for Revised Gaseous Emission Regulations for 1984 and Later Model Year Light-Duty Trucks and Heavy-Duty Engines

July 1983

Standards Development and Support Branch
Emission Control Technology Division
Office of Mobile Sources
Office of Air, Noise and Radiation
U.S. Environmental Protection Agency

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Table of Contents

Table of Contents (cont'd.)

I. Introduction

On January 13, 1982, the Environmental Protection Agency (the Agency) published a Notice of Proposed Rulemaking (NPRM) in which the Agency considered revised gaseous emission regulations for 1984 and later model year light-duty trucks and heavy-duty engines. Although the major thrust of this action was to propose non-catalyst emission standards for heavy-duty engines, the Agency also requested and received comment on a large number of other issues related to the 1984 emission control requirements for light-duty trucks and heavy-duty engines.

To seek further clarification and comment on issues raised by the initial NPRM, several opportunities were offered for comment, including a further request for comments published in the Federal Register on March 12, 1982. A final rule was published in January 1983. Also, to achieve final resolution on the useful-life requirement, a further NPRM on the 1985 light-duty truck and heavy-duty engine useful-life requirements was published in January 1983.

This document presents a Summary and Analysis of Comments received in response to the NPRM and the subsequent requests for comment mentioned above. The useful-life discussion presented as Primary Issue 2 serves as the study of the useful-life requirements discussed in the Federal Register Notice of April 13, 1981. The transient test study undertaken as a result of the same Federal Register notice is included as Appendix B.

II. List of Commenters

1. American Motors Corporation (AMC)
2. Caterpillar Tractor Company
3. Chrysler Corporation
4. Cummins Engine Company
5. Engine Manufacturers Association (EMA)
6. Ford Motor Company
7. Freightliner Corporation
8. General Motors Corporation (GM)
9. U.S. Senator Gary Hart
10. Hino Motors, Limited
11. International Harvester Company (IHC)
12. League of Women Voters of Carson City, Nevada
13. League of Women Voters of the Doyleston Area
14. League of Women Voters of the United States
15. Mack Trucks, Inc.
16. Manufacturers of Emission Controls Association (MECA)
17. Mercedes-Benz of North America (MB)
18. Mrs. W. H. Morse
19. Motor Vehicle Manufacturers Association (MVMA)
20. National Association of Van Pool Operators (NAVPO)
21. National Automobile Dealers Association (NADA)
22. Natural Resources Defense Council (NRDC)
23. New York City League of Women Voters
24. Regional Air Pollution Control Agency, Dayton, Ohio
25. Frances Scherer
26. Toyota Motor Company
27. Western New York Allergy and Ecology Association
28. Volkswagen of America (VWoA)

A. Primary Issues

1. Issue: Technological Feasibility

Summary of the Issue

This analysis addresses the technological feasibility of emission standards for heavy-duty engines (HDEs) for 1985 and later model years. Two separate analyses are contained herein: an analysis and derivation of hydrocarbons (HC) and carbon monoxide (CO) emission standards for 1985 which are achievable without catalysts, and an analysis of the feasibility of catalyst-based standards for 1987 and later model years.

A. NON-CATALYST STANDARDS FOR 1985

Summary of the Comments/Synopsis of Events

There have been several iterations of EPA action and public reaction as this issue has developed over time. For purposes of clarity, a brief synopsis of significant events is appropriate; public comments to each iteration will be summarized as they chronologically occurred.

On January 21, 1980, EPA promulgated final regulations for the control of gaseous emissions from HDEs applicable to the 1984 and later model years.[1] The regulations included the new EPA transient test cycles, the full useful-life concept, and statutory emission standards of 1.3 grams per brake horsepower-hour (g/BHP-hr) HC, 15.5 g/BHP-hr CO, and 10.7 g/BHP-hr oxides of nitrogen (NOx).* Compliance with these emission standards on the transient test almost certainly requires the use of oxidation catalysts on heavy-duty gasoline engines (HDGEs).

On April 6, 1981, the Vice President's Task Force on Regulatory Relief announced that EPA would propose emission standards for 1984 which would not require the use of catalysts. It was intended that this action defer the capital investments required for catalyst development, and thus provide economic relief to an industry beset by recession and decreased sales. On January 13, 1982, EPA officially proposed non-catalyst emission standards of 1.3 HC/35.0 CO/10.7 NOx for 1984 HDEs.[2]

The associated Draft Regulatory Analysis[3] tentatively concluded that emission standards of 1.3 HC/35.0 CO were feasible without catalysts. The analysis discussed the transient test in great detail, and presented modal emissions

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* All standards are based upon the EPA HDGE transient cycle.

from 12 1979 model year HDGEs. Emission levels for current technology were discussed, as were the emissions impact of specific operational modes of the transient test. By comparing low to high emitting engines and by identifying specific technologies and calibrations, EPA made the judgment that 1.3/35.0 appeared feasible for 1984 non-catalyst HDGEs.

In public comments to the Notice of Proposed Rulemaking (NPRM) received by April 1982,[4,5] only Ford Motor Company (Ford) and General Motors (GM) submitted transient test emissions data. Chrysler and International Harvester Company (IHC) did not comment on technological feasibility, and in fact, indicated that they were leaving the HDGE market for reasons unrelated to these regulations. (Both Chrysler and IHC have since indicated that they may reverse these decisions.)

In its comments, Ford stated its position as follows:

> "Ford believes that its recommended 3.3 HC and 42 CO g/BHP-hr standards for the 1985 model year HDGEs represent the lowest levels achievable without unreasonable sacrifices in performance, fuel economy, or driveability."

General Motor's comments stated that:

> "Review of available 1984 prototype HDGE development data indicated that most GM HDGEs could achieve low-mileage emission levels of approximately 2.0 HC and 32 CO g/BHP-hr."

General Motors subsequently recommended emission standards of 2.9 g/BHP-hr HC and 43.0 g/BHP-hr CO, on the basis of increased certification deterioration factors and assumed production variability. GM also argued that standards of 3.5 g/BHP-hr HC and 70 g/BHP-hr CO were justified on the basis of air quality needs, fuel economy, and cost. In comments and later discussions, GM also raised the point that the emission control strategies required to reduce HC and CO emissions to EPA's proposed standards could severely degrade engine durability. GM claimed that the need for full-power mixture enleanment and increased oxidation of pollutants in the exhaust system will raise in-cylinder and exhaust system temperatures to excessive levels. GM said that this will not necessarily be seen on EPA's transient test procedure, but more than likely will be seen in severe in-use applications for engines calibrated to meet EPA's proposed requirements.

Emissions data for 1984 prototype HDEs, as submitted by GM and Ford in April of 1982, are listed in Table 1-1.

Table 1-1

Manufacturers' 1984 Prototype Heavy-Duty Engine Data (submitted by April 1982)

Manufacturer	Engine Displacement	Emission Control System	g/BHP-hr* HC	CO	NOx	BSFC lb/BHP-hr
Ford	4.9L	AIR/EGR/EFE	1.66	23.2	7.68	0.560
Ford	6.1L	AIR/EGR	2.33	28.8	7.25	0.654
Ford	7.0/7.5L	AIR/EGR	2.21	24.3	4.82	0.633
GM	292 in^3	AIR/EGR	1.65	17.42	6.52	--
GM	350 in^3	AIR/EGR	1.76	25.07	5.25	--
GM	366 in^3	AIR/EGR	1.33	20.19	6.91	--
GM	454 in^3	AIR/EGR	0.90	20.93	7.42	--

* EPA cycle based.

In reviewing these comments, EPA staff felt that additional engineering data were required to determine the lowest emission standards achievable without catalysts. Specific requests for more detailed information were made to HDGE manufacturers on June 17, 1982;[6] Ford provided additional engineering data, GM provided a more detailed qualitative discussion and emission data (see Table 1-2) but declined to submit detailed engineering data, and Chrysler and IHC were unable to provide any additional data or information. At a meeting with EPA staff on January 28, 1983, representatives of GM again made the claim that 1.3/35.0 non-catalyst emission standards would adversely affect engine durability and fuel economy.

In a <u>Federal Register</u> notice of January 12, 1983, EPA officially delayed the 1984 model year emission requirements until 1985. This revision of the 1985 standards was justified on the basis of leadtime,* economics,* and the number of other issues yet to be resolved (i.e., alternative test cycles, useful life, etc.).

Reviewing all comments and data available at the time, and taking into account the additional year of development leadtime, EPA then analyzed the level of non-catalyst emission standards achievable for 1985. This analysis[8] went hand-in-hand with an EPA staff paper[7] in which both short and long-term strategies for the control of HDGE emissions were discussed. The staff paper, which was released for public comment on March 16, 1983, developed a control scenario whereby lighter heavy-duty gasoline trucks (HDGTs) would be equipped with catalysts in the 1987-88 time frame, and heavier gasoline truck engine standards would remain at non-catalyst levels.** At the same time, the staff paper summarized EPA's most recent analysis of 1985 standard feasibility, which had recommended non-catalyst standards of 2.5/35.0 g/BHP-hr.

This feasibility analysis,[8] the summarized results of which were discussed at an April 6, 1983 Public Workshop, was also distributed for public comment on April 12, 1983. The analysis recommended that non-catalyst emission standards of 2.5/35.0 g/BHP-hr be promulgated for 1985. This recommendation revised EPA's earlier conclusion that a 1.3 g/BHP-hr HC was feasible for 1984 without catalysts.

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* See appendix, Chapter 3 of the Transient Test Study.

** See the POST-1985 EMISSION STANDARDS section of this issue.

Table 1-2

Additional Emission Data
Provided by GM in August of 1982[5]

Low-Mileage Emissions*

Engine	HC	CO	NOx	BSFC
GM 292	2.17	24.9	6.80	.639
GM 350-2V	1.57	28.2	6.11	.604
GM 350-4V	1.99	27.2	5.14	.649
GM 366	.75	17.9	3.57	.582
GM 454	1.01	22.2	4.28	.666

* EPA cycle-based g/BHP-hr. GM claimed that these data are representative of heavy-duty gasoline engine emission control systems and calibrations which, in August of 1982, were believed to be "at least plausible for production." None of these engine configurations had been durability tested, but all had been driven in a small sample of vehicles and had been determined to provide commercially acceptable performance and driveability.[5]

EPA's more recent conclusion that the non-catalyst HC standard must be relaxed was based upon several considerations. A review of the actual development data submitted by Ford and GM in April 1982 (see Table 1-1) indicated that substantial progress had been made in reducing emissions. However, all but one engine family were still well above the low-mileage target emission levels needed to assure compliance with a 1.3 g/BHP-hr HC standard. (All engine families were very close to the low-mileage target level for CO more than two years before required compliance, hence no relaxation of the CO standard was recommended.) EPA's analysis then discussed the remaining technology which could be applied to reduce HC emissions further. Since only Ford supplied detailed engineering data in response to EPA's June 17, 1982 request, only an analysis of Ford's product line was possible. (Since GM's engines in Table 1-1 all exhibited HC emission rates less than most Ford engines, it was judged that GM would have no problem complying with an HC emission standard based upon Ford's higher emitting engines.) Using data provided by Ford, EPA concluded that further reductions in HC were certainly possible, and that compliance with a 2.5 g/BHP-hr HC standard in 1985 would be possible even for Ford's highest emitting engine. HC standards less than 2.5 g/BHP-hr were considered, but were rejected on the basis of reasonable risk of non-compliance and fuel economy penalties for higher emitting engines. In summary, 2.5/35.0 were recommended as reasonable interim emission standards.

In comments[5] received by May 6, 1983, the conclusions and methodology of EPA's latest feasibility analysis[8] were again disputed. These comments are summarized below for each commenter.

Chrysler

Chrysler again commented that it was in no position to recommend specific interim standards, primarily because its transient test facility was not yet operational. Based upon testing performed for it under contract, however, Chrysler did not believe that the 35.0 g/BHP-hr CO standard was feasible even with a catalyst. Chrysler recommended continued provision of the 9-mode steady-state option until 1986.

Engine Manufacturer's Association (EMA)

The EMA and its member companies have not disputed the feasibility of the 1.3/35.0 g/BHP-hr standards for heavy-duty diesel engines (HDDEs).

Ford

Ford provided a comprehensive review of the emissions status of its HDGE product line. Ford's data showed that significant progress has been made in reducing emissions. However, Ford disputed EPA's feasibility analysis, characterizing it as overly optimistic. "EPA's suggestion that manufacturers not only can meet 2.5/35.0 but can also achieve substantial further reductions is overstated." Ford also argued that "EPA has overestimated the capabilities of some heavy-duty engines," notably Ford's 6.1L-4V (Ford's largest seller and occupant of the heaviest gasoline vehicle weight classes). The major problem associated with feasibility, according to Ford, is not so much the effectiveness of technology but rather the relatively low target levels which are forced upon a manufacturer by the full useful-life and Selective Enforcement Audit (SEA) requirements. Ford recommended half-life standards of 2.19/42.6 based upon the MVMA cycle; according to Ford, these are equivalent to full-life EPA cycle standards of 3.07/47.8.

General Motors

General Motors vigorously disputed the conclusions of EPA's feasibility analysis, characterizing the analysis as "entirely inadequate," and mostly "guesswork." GM insisted that EPA's engineering judgment was based upon limited and outdated emission data, very few research studies, and limited, incomplete data supplied by manufacturers. GM also criticized EPA for "engineering on paper," for failing to construct and evaluate through testing, any engine conforming to EPA's design recommendations, and for failing to generate any current data.

General Motors qualitatively discussed several engineering aspects of achieving low levels of HDGE emissions without catalysts. GM also discussed durability, driveability, and fuel economy problems associated with "unreasonably stringent standards." In GM's opinion, forced compliance with the 35.0 g/BHP-hr CO standard would preclude the production of reasonably durable engines. Indeed, GM argued that the poor performance of engines produced under these emission constraints would invite tampering in the field.

General Motors questioned EPA's apparent policy of establishing stringent interim standards, especially given the major changes occurring in the 1987-88 timeframe, the "risk to the heavy-duty industry," and "the lack of demonstrated feasibility." GM recommended half-life non-catalyst emission standards of 2.9/43.0 (EPA cycle) for 1985.

With respect to data, GM submitted a large confidential discussion of various aspects of its development work. Included were qualitative discussions of GM's calibration strategies and hardware for complying with 1.3/35.0 g/BHP-hr standards, qualitative discussions of GM's engine durability experience, a description of GM's in-house durability test procedures, comparisons of 1983 versus 1985 prototype timing and air/fuel (A/F) calibrations, actual test reports from characterizations of wide-open throttle (WOT) timing versus detonation requirements, on-road fuel economy data, and actual test reports from exhaust system temperature and durability studies.

On the other hand, no new emission data were submitted by GM; the latest data indicating the position of GM's product line with respect to compliance was that submitted by April and August of 1982 (see Tables 1-1 and 1-2). GM went on to characterize the April 1982 data as being unrepresentative of its true compliance capability, having been acquired long before subsequent testing discovered durability problems. Furthermore, GM stated that its test experience and comments only address the feasibility of the 1.3/35.0 standards. GM claimed that it had only just begun to evaluate the implications of the 2.5/35.0 standards. Nevertheless, GM recommended that EPA promulgate half-life standards of 2.9/43.0 (EPA cycle) g/BHP-hr for 1985.

Analysis of Comments

Overview

This analysis will develop and recommend non-catalyst standards for 1985 and later model year HDGEs. Aside from the specific hardware and applicable emission control techniques to be addressed, it is equally important to address the effect of other factors on the stringency of the interim emission standards. The most important of these other factors are the full useful-life concept, the SEA requirements, and the correlation between the EPA and MVMA test cycles. These issues will be discussed first, because of their inherent impact on standard stringency.*

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* The relationship of two of these factors to low-mileage emission targets and emission standards is typically expressed as:

$$\frac{1}{AQL} [\text{Emission Standard} - \text{DF}] = \text{Low-mileage target.}$$

The analysis will then review the status of the HDGE manufacturers with respect to current emission levels of their "best effort" engines, where possible. As in earlier analyses, judgments will be made whether further reductions can be made for the 1985 model year.

Deterioration Factors

Manufacturers are required to correct "low-mileage" emission levels from certification engines for expected in-use deterioration. Current requirements, and those applicable for 1985, require that deterioration be assessed in an additive fashion. Current deterioration factors (DFs) have largely been derived from durability testing performed on engine dynamometers. Very little, if any, data exists on the degree of deterioration which actually occurs in use. Dynamometer durability testing results have never been validated, and there is substantial uncertainty as to the magnitude of true in-use DFs for all HDEs.

On the other hand, the process of compliance in 1985 will be based upon DFs derived and supplied by the manufacturer in whatever manner they deem appropriate. Techniques of DF derivation can range from simple engineering judgment to continued use of dynamometer testing to actual in-use tests. Given the lack of an officially imposed method, one would expect manufacturers to base their DF determinations upon past practice and experience.

Certification DFs for HDGEs have typically been quite small. Table 1-3 presents a summary of official certification DFs for Ford's and GM's HDGEs for the 1983 model year. In almost all cases, emissions decreased after completion of durability test runs on the engine dynamometers. Substantial changes, however, are being made to engine hardware for the 1985 model year. This new hardware will also be required to maintain compliance for a full useful life (110,000 miles), as opposed to the previous half-life (50,000 miles) requirement. Therefore, the DFs in Table 1-3 may be somewhat less than DFs derived and used for 1985.

In past analyses, EPA has converted from half- to full-life DFs by assuming linear deterioration (i.e, the full-life DF is equal to the half-life DF multiplied by 110,000/50,000, or 2.2). This methodology is straightforward, and fits the general trend of deterioration observed in dynamometer testing of non-catalyst engines. While EPA has confidence in this adjustment, assessing the deterioration rates of new engine hardware not yet in production is more problematic.

Based upon current prototypes, 1985 HDGEs will likely be equipped with the following hardware: large dual air pumps,

Table 1-3

1983 Model Year Certification
Deterioration Factors (DFs) for Ford and GM HDGEs

Manufacturer/Engine Family	Certification DFs* HC	CO
Ford 4.9L "Q"	0.00	0.00
Ford 6.1L "E" - 2V	0.00	1.91
Ford 6.1L "E" - 4V	0.00	1.91
Ford 7.0L "E"	0.00	0.00
Ford 7.5L "E"	0.00	0.00
Ford 5.8L (W) "E"	0.00	0.48
GM DGM07.0ABB4:		
- L86 (366 CID)	0.00	0.00
- L43 (427 CID)	0.00	0.00
GM DGM07.4ABB9:		
- LF8 (454 CID)	0.00	0.00
GM DGMO4.8ABA6:		
- L25 (292 CID)	0.00	0.00
GM DGMO5.7ABB9:		
- LF5 (350 CID - 2V)	0.00	0.00
- LS9 (350 CID - 4V)	0.00	0.00

* Additive g/BHP-hr, half-life basis.

EGR, early fuel evaporation systems, heated air intake systems, and automatic chokes. Carburetor and ignition timing calibrations will be different from current models, as will manifold designs and air injection systems. In-cylinder and exhaust system temperatures will be hotter than those of current engines because of leaner mixtures and increased thermal reaction. As a total package, these modifications are uncharacterized in heavy-duty engine applications with respect to deterioration and long-term performance. Given the significant changes from 1984 to 1985, it is reasonable to expect that manufacturers will run at least some dynamometer durability tests out to the full useful-life equivalent of 3,300 hours.

Quantification of expected deterioration is by necessity somewhat speculative, but there are a number of reasons why 1985 DFs should not be exceptionally high:

1. No inherent increase in deterioration rates should be expected from recalibrations of ignition timing or carburetors. Deterioration rates of this hardware have been previously established, and simple changes to timing settings or fuel flow rates should not alter the functional durability of the hardware.

2. Catastrophic or significant causes of deterioration to minor components will be identified during accelerated durability testing, at which time corrective redesign can take place.

3. If problems arise with component-related durability, especially during dynamometer testing corresponding to the second half of the useful life, new maintenance provisions can be specified to alleviate the problem.

4. Prototype air injection systems are merely larger versions of existing systems whose durability performance have already been characterized. Other changes simply represent changes to static piping and manifolds; these hardware experience minimal emission-related deterioration.

5. Finally, most of the hardware new to HDGEs have already been successfully used on production LDVs and LDTs for several years. EPA expects the manufacturers to have acquired considerable experience with the design, maintenance, and in-use durability of such hardware. This experience is directly relatable to HDGEs.

Given the above, and given the DFs presented in Table 1-3, EPA does not expect large DFs to be used or needed for 1985.

Referring to Table 1-3, only two engine families exhibited a non-zero CO DF for 1983 (the Ford 6.1L and 5.8L). EPA does not expect CO deterioration rates to be significantly different from 1983; CO emission control is primarily a function of leaner carburetor calibration and improved air injection, neither of which should affect durability to any great extent. For purposes of this analysis, EPA will use the worst case DF from 1983 (1.91 for the Ford 6.1L), corrected from half- to full-life (i.e., 1.91 multiplied by 110,000/50,000 or 2.2 to equal 4.20).

Quantification of HC deterioration is more speculative. All 1983 Ford and GM engine families exhibited HC DFs of 0.00 or less, but there is some reason to believe that HC DFs may increase in 1985. Cold start emission control apparatus is new, as would be more elaborate ignition timing controls (if used). These systems will primarily affect HC emissions. On the other hand, systems of this type have already been used for several years on production LDVs and LDTs, and EPA presumes that the manufacturers have well characterized their performance. For purposes of this analysis, EPA will use the same additive DF used in the earlier analysis,[8] a DF of .25. This is likely to be a representative DF, given the performance of current engines, the existing experience with such equipment on LDTs and LDVs, and EPA's assumption of a moderate increase in DFs for 1985.

SEA Requirements

SEA testing requirements are scheduled to take effect in the 1986 model year. Therefore, a manufacturer cannot be subjected to the jeopardy of failing a production line audit until 1986. For this reason, it is entirely reasonable to ignore SEA requirements in establishing emission target levels for 1985. On the other hand, it is also reasonable to expect that a manufacturer would wish to conclude development work prior to 1985, and rely upon carryover for the next year to avoid continued recertification expenses. This feasibility analysis will include the effect of SEA requirements in establishing feasible emission standards for 1985, since recertification in 1986 would not be desirable from the manufacturers' standpoint. However, in the event that one or two engines may appear to be having difficulty in achieving SEA-based low-mileage target levels for 1985, EPA cannot ignore the additional flexibility provided manufacturers by the effective relaxation of low-mileage target levels afforded by EPA's deferral of SEA requirements.

Production line emission variability is fairly well characterized. EPA's earlier analysis[8] and Ford's May 6, 1983 comments[5] used numerical values of 1.136 and 1.200, respectively, for HC, and 1.266 and 1.300, respectively, for CO. (GM has previously used a 40 percent AQL factor of 1.10 for all gases.[5]) EPA's and Ford's values are essentially in agreement; for purposes of this analysis, arithimetic averages of Ford's and EPA's numbers will be used (i.e., 1.168 for HC and 1.283 for CO), and represent conservative values in EPA's judgment. For worst case engines, however, a value of 1.000 would be available for the 1985 model year.

Alternative Test Cycles

EPA's earlier analyses[3,7,8,9] were all based upon EPA cycle test results, and the emission standards discussed were also based upon the EPA cycle. All of the latest "best effort" emission data, however, is MVMA cycle based. For purposes of this analysis, MVMA cycle-based standards will be developed from this "best effort" data. For purposes of comparability with previous analyses, equivalent EPA cycle-based standards will also be presented.*

Only Ford gave EPA specific information on the current emissions status of their product line. As in its earlier analysis,[8] EPA will evaluate the feasibility of emission standards for HDGEs based largely upon Ford's data. In the absence of any specific emissions data to the contrary, and by reviewing the latest GM emission data made available to EPA in August of 1982, EPA will assume that the emissions capabilities of GM's engines are not substantially different from Ford's. The emissions capabilities of Chrysler's and IHC's engines are unknown, however, the necessary technologies are widely available and well understood. EPA does not expect the emissions capabilities of Chrysler's or IHC's engines to be fundamentally different from those of Ford or GM.

Current Status of HDGE Emission Levels

Tables 1-4, 1-5, and 1-6 present EPA's evaluation of Ford's "best effort" data; Table 1-5 also includes GM's most recent data. Clearly, significant improvements have been made since 1979 and earlier model years (see Figures 1-1 and 1-2). Using Ford's recent MVMA cycle-based low-mileage results, these levels have been converted to equivalent emission standards, both in terms of the MVMA cycle and the EPA cycle (see Tables

* Equivalent EPA cycle-based emissions will be based upon the following equations (derived in Issue A.3. of this Summary and Analysis of Comments):

HC: MVMA = .886 (EPA) - 0.318
CO: MVMA = 1.03 (EPA) - 4.04

Table 1-4

Review of Ford's "Best Effort" Data,[5] Estimated Current Attainable MVMA Cycle-Based Emission Standards*

May 1983 Data

Ford Engine Model	Low-Mileage Emission Results*		Equivalent Deteriorated HC Emission Standard*	Equivalent Deteriorated CO Emission Standard*
	HC	CO		
4.9L-1V	1.21(1.72)	25.0(28.2)	1.66(2.26)	36.3(40.4)
6.1L-2V	1.08(1.58)	23.4(26.6)	1.51(2.09)	34.2(38.4)
6.1L-4V	1.70(2.28)	28.5(31.6)	2.24(2.91)	40.8(44.7)
7.0L-4V	1.50(2.05)	17.7(21.1)	2.00(2.65)	26.9(31.3)
7.5L-4V	1.36(1.89)	23.6(26.8)	1.84(2.46)	34.5(38.6)

* MVMA cycle based, g/BHP-hr; the numbers in parenthesis are EPA cycle based, g/BHP-hr.

Table 1-5

Currently Attainable
EPA Equivalent Emissions Standards

Engine Family	Equivalent, Deteriorated EPA Cycle-Based HC Emission Standard*	Equivalent, Deteriorated EPA Cycle-Based CO Emission Standard*
May 1983 Data (derived from Table 1-4)**		
Ford 4.9L-1V	2.26	40.4
Ford 6.1L-2V	2.09	38.4
Ford 6.1L-4V	2.91	44.7
Ford 7.0L-4V	2.65	31.3
Ford 7.5L-4V	2.46	38.6
August 1982 Data (derived from Table 1-2)		
GM 292	2.78	36.1
GM 350-2V	2.08	40.4
GM 350-4V	2.57	39.1
GM 366	1.13	27.2
GM 454	1.43	32.7
April 1982 Data (derived from Table 1-1)		
Ford 4.9L	2.19	34.0
Ford 6.1L	2.97	41.2
Ford 7.0/7.5L	2.83	35.4
GM 292	2.18***	26.5***
GM 350	2.31***	36.4***
GM 366	1.80***	30.1***
GM 454	1.30***	31.1***

* EPA cycle-based, g/BHP-hr, assumes deterioration and includes SEA requirements.

** Calculated by first correcting MVMA to EPA low mileage emissions, then adjusting for SEA and deterioration.

*** These emission levels were claimed by GM in May of 1983 to have promoted unacceptable engine durability and performance, and were reported to EPA before discovery of such problems.

Table 1-6

Compliance Ability of Ford's Product Line at Various Levels of EPA Cycle-Based Emission Standards (May 1983 data)

EPA Cycle-Based Emission Standards		Number of Engine Models in Compliance by May 1983*
HC	CO	
1.3	35.0	0 out of 5
2.5	35.0	1 out of 5
2.5	40.0	3 out of 5
2.6	40.0	4 out of 5
2.9	45.0	5 out of 5

* Assumes deterioration; includes 1986 SEA requirements.

Figure 1-1

CO Emissions (EPA Cycle-Based) from Ford HDG Engines
(Note: Engines of similar displacement over time are considered to be in the same "family.")

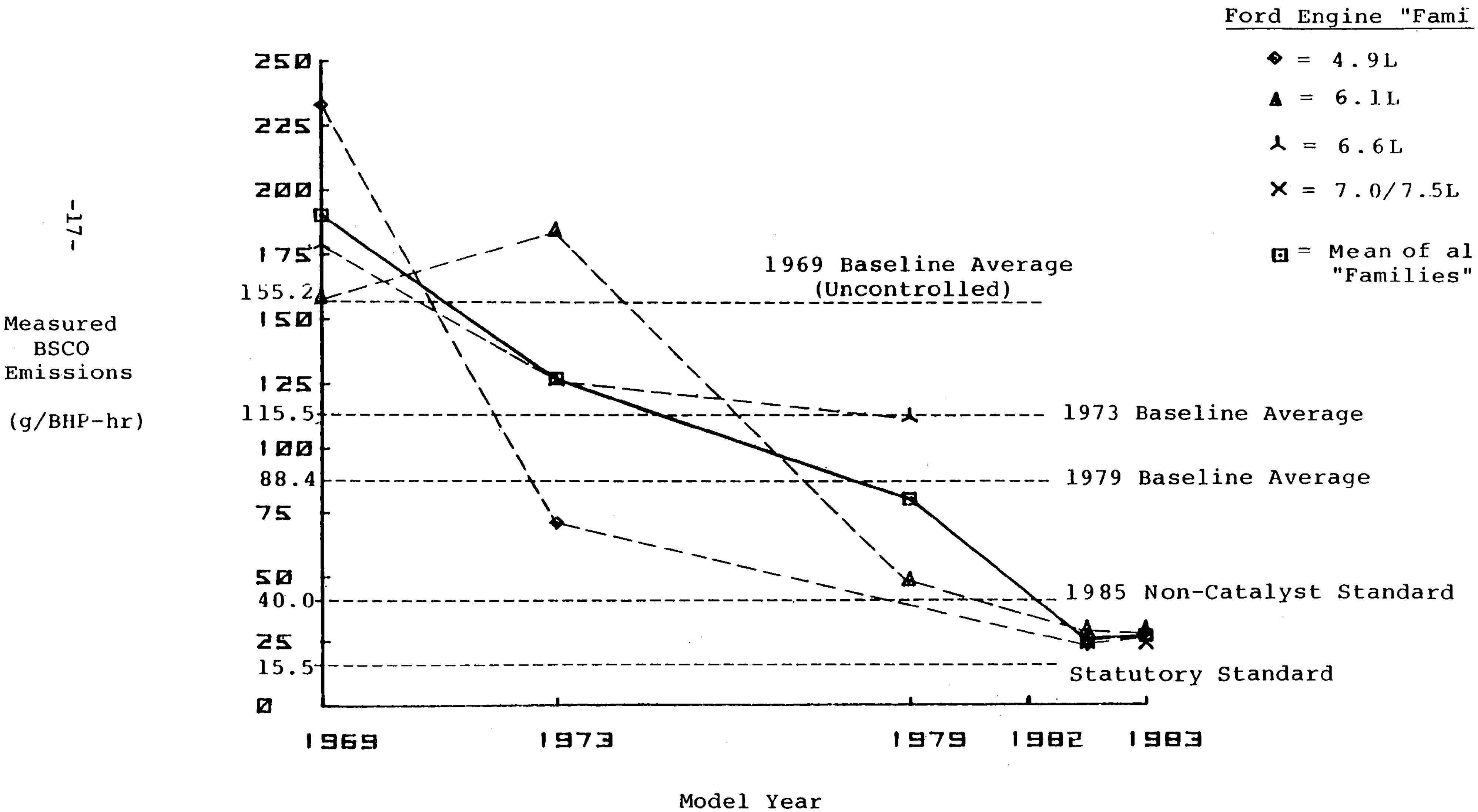
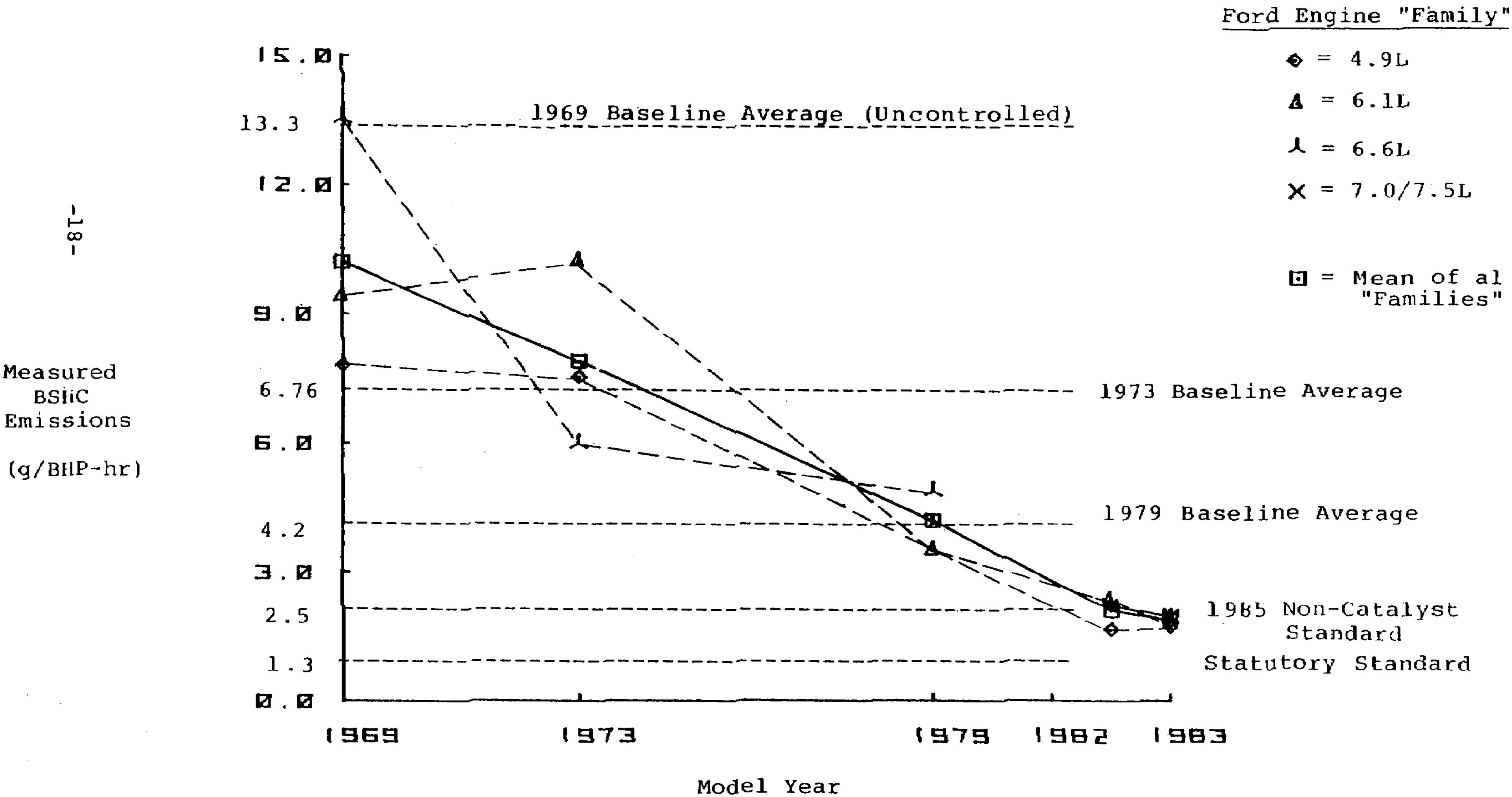


Figure 1-2

HC Emissions (EPA Cycle-Based) from Ford HDG Engines
(Note: Engines of simialr displacement over time are
considered to be in the same "family.")



1-4 and 1-5). Table 1-6 summarizes the ability of Ford's engines, in May of 1983, to comply with a variety of potential emission standards.

Tables 1-5 and 1-6 indicate that only two of Ford's five engine models would today exceed an HC standard (EPA cycle based) of 2.5 g/BHP-hr (and one marginally so), whereas four out of five would exceed the 35.0 g/BHP-hr CO standard. An important observation to make is the fact that very little has changed in Ford's compliance ability between April 1982 and May 1983 (see Table 1-5). Ford made the statement in their comments of May 6, 1983 that significant progress had been made relative to Ford's reported status of April 1982. However, EPA's present analysis indicates that much of the reported progress was illusory, arising primarily from a change in test cycles. (The April 1982 data were EPA cycle-based; the May 1983 data were MVMA cycle-based.)

Based solely upon Ford's May 1983 data, the current critical range of feasibility apparently lies between 2.5-2.6 g/BHP-hr HC and 35.0-40.0 g/BHP-hr CO (EPA cycle based). Assuming for the moment that there is little practical difference between a 2.5 and 2.6 HC standard, then relaxing the proposed CO standard of 35.0 to 40.0 would allow all but one of Ford's engines to comply with 1985 requirements in May of 1983, taking into account deterioration and 1986 SEA requirements for 1985. Reviewing GM's latest data (presented in Table 1-5), this relaxation would also allow all but one of GM's engines to comply, even if no improvement in emission levels have been made since August of 1982.

1985 Standards Derivation

EPA's draft feasibility analysis[8] attempted to evaluate the detailed calibrations, hardware, and associated emission levels of Ford's April 1982 engines. Using these facts as starting points, EPA surmised how additional emission reductions could be made for the few engines which the April 1982 data indicated actually required further work to meet 2.5 g/BHP-hr HC and 35.0 g/BHP-hr CO (see Tables 1-1 and 1-5). Emission reductions were predicted based upon established principles of emissions engineering, whereby given changes of calibrations produce predictable trends in emissions.

Both Ford and GM took issue with EPA's analysis. Criticism of EPA abounded, but no approaches for further emission control were recommended as having promise. GM harshly criticized EPA for drawing conclusions from a limited data base, despite its refusal to provide EPA with specific calibration information. Ford was less critical than GM, discussing several of EPA's evaluations and indicating where Ford thought they were incorrect or why they would prove ineffective. Despite Ford's presentation on the emissions status of their product line, EPA still has only generalized information as to the specific emission control techniques attempted, which were discarded, and which remain available (with and without trade-offs). Furthermore, without specific engine calibration information it is difficult for the Agency to identify which levels of emission standards represent the most stringent standards possible without unreasonable impacts on cost or fuel economy, as EPA is required by law to promulgate. Commenters are correct in maintaining that EPA is not close enough to engine development efforts to anticipate engine specific problems which arise as each control technique is applied to each engine. For this reason alone, the manufacturers are responsible for providing EPA with the detailed, unbiased information it needs to make reasoned decisions.

Without such information, EPA can only review the best available data, and make a judgment as to what represents reasonable interim standards, given the state of current engine development and given the remaining leadtime until 1985.

As shown in Table 1-6, only one of Ford's engines would significantly exceed an HC standard of 2.5 g/BHP-hr. The remaining engine, the 6.1L-4V, would require a 16 percent reduction in low-mileage emissions to meet the 2.5 standard (see Table 1-7). If Ford takes advantage of the certification flexibility provided by EPA for 1985 (SEA requirements do not apply), the 6.1L-4V would already meet a 2.5 standard if only deterioration is included with the low-mileage emissions to determine compliance. In short, one extra year of leadtime is available, if necessary, for attaining what appears to be a modest reduction in HC emissions. EPA will not speculate as to which technologies will be used to achieve the reduction, although in the worst case ignition timing retard is available. More importantly, EPA cannot allow the technological laggard to set the pace for standard setting; to do so surrenders the gains already achieved with the majority of engines, and does little to motivate a manufacturer to lower emissions from its engines.

To some extent, the same argument holds true in determining a feasible CO standard. However, as shown in Table 1-6, the majority of Ford's product line will require additional work to achieve the 35.0 g/BHP-hr CO standard. Some reduction in low-mileage emissions will be necessary for four out of five engines, including a substantial reduction (26 percent) for the 6.1L-4V family (see Table 1-7). Given the

Table 1-7

Percentage Reductions in Low Mileage Target (LMT) Emissions Required to Comply With Emission Standards of 2.5 g/BHP-hr HC and 35.0 g/BHP-hr CO (EPA cycle based)

Engine Family	Required HC LMT Reductions (%)	Required CO LMT Reductions (%)
Ford 4.9L-IV*	0	16
Ford 6.1L-2V*	0	10
Ford 6.1-4V*	16	26
Ford 7.0L-4V*	5	0
Ford 7.5L-4V*	0	11
GM 292**	9	2
GM 350-2V**	0	13
GM 350-4V**	1	10
GM 366**	0	0
GM 454**	0	0

* May, 1983 data.
** August, 1982 data.

industry's claims of decreased engine durability with further enleaned fuel mixtures at WOT, and given the remaining leadtime, there appears to be some risk in a 35.0 g/BHP-hr CO standard. If, on the other hand, the emissions from Ford's worst emitter (again the 6.1L-4V) were to be reduced to the level of the remainder of Ford's fleet, an emission standard of 40.0 g/BHP-hr would be required. Again, EPA rejects the idea that the technological laggard set the pace of emissions reduction; therefore, a standard greater than 40.0 g/BHP-hr would be unjustified.

Selecting a CO standard between 35.0 and 40.0 g/BHP-hr then becomes an exercise in evaluating trade-offs. Promulgation of 35.0 g/BHP-hr, or any standard which requires the majority of the product line to achieve further reductions, will increase the risk of durability problems, and at the same time direct development efforts away from the 1987 standards. Requiring the highest emitters to achieve further reductions, however, is both appropriate and necessary to retain reductions already achieved. From Table 1-5, EPA notes that the majority of Ford's engines (according to the latest data) lie at the high end of the 35.0-40.0 g/BHP-hr range.

EPA does not believe that compliance with a 35.0 g/BHP-hr CO standard is infeasible. However, some additional development work would be necessary for four of Ford's five families, and significant work for one family. Given the fact that some development work is still required to meet both the 2.5 g/BHP-hr HC standard and a 40.0 g/BHP-hr CO standard, given EPA's desire not to preempt significant development efforts from the 1987 model year, given the fact that many of the engines for which data is currently available exhibit CO emissions closer to 40.0 g/BHP-hr than 35.0, and given the risk to engine durability entailed in meeting a 35.0 g/BHP-hr CO standard within short leadtimes, EPA believes that 40.0 g/BHP-hr would be a reasonable non-catalyst CO standard for 1985.

EPA's evaluation of the latest GM data leads it to the same conclusions. As can be seen in Table 1-5, GM's August 1982 data indicates that only a single engine would significantly exceed standards of 2.5/40.0, and it would only exceed the 2.5 HC standard. GM has repeatedly expressed concern about the durability implications of stringent non-catalyst CO standards. As noted in Table 1-7, some of GM's engines still require reductions in low-mileage CO emissions to meet a 35.0 g/BHP-hr standard. However, the lack of specific calibration information for GM's engine has made EPA's review of the reasonableness of GM's claims difficult, at best. (For example, EPA would not consider durability data taken on engines with WOT A/F calibrations leaner than stoichiometry to be at all representative; such calibrations would be unnecessary for compliance and understandably severe on durability.) EPA notes that GM's criticism of EPA's earlier feasibility analysis only addressed GM's concern with complying with 1.3/35.0 standards. The latest GM and Ford data indicate that low-mileage compliance with standards of 2.5/40.0 g/BHP-hr represents no problem whatsoever for almost all engine families; the feasibility issue essentially breaks down to the level of emission standards which would not degrade engine durability or performance. EPA believes that relaxation of the proposed 1.3 HC standard to 2.5 will preclude the need for substantial ignition timing retard, both preserving fuel economy and precluding increased exhaust temperatures. EPA also believes that relaxation of the proposed 35.0 CO standard to 40.0 will also preclude the need for A/F calibrations lean enough to promote excessively high temperatures and durability problems. EPA bases these judgments on the current performance of Ford's product line, upon Ford's claims that these emission levels will not impair engine durability, upon GM's own test data, and upon the lack of GM's comments and data to the contrary for engines designed to meet emission standards at these levels.

Conclusion

Revised gaseous emission standards of 2.5 g/BHP-hr HC and 40.0 g/BHP-hr CO (or 1.9 g/BHP-hr HC and 37.1 g/BHP-hr CO based upon the MVMA cycle) are feasible without catalysts, will not degrade engine performance or durability, and therefore should be promulgated for the 1985 model year.

B. POST-1985 EMISSION STANDARDS

Summary of Comments/Synopsis of Events

Soon after the decision was made to propose non-catalyst standards for the 1985 model year, EPA began evaluating when further progress towards the statutory standards would be appropriate for gasoline engines. It is generally accepted that compliance with the statutory 1.3 HC/15.5 CO standards will require oxidation catalysts. (Diesel engines easily comply with the statutory HC and CO standards.)

EPA has never altered its conclusions of January 21, 1980[1,9] that catalysts are ultimately feasible for use on HDGTs. The justification for deferring catalyst-based standards beyond 1984 was based principally upon economic grounds and leadtime concerns, not technical feasibility.

On March 16, 1983, EPA distributed a staff paper[7] for public comment, and subsequently held a Public Workshop on

April 6, 1983. The staff paper presented options for the long-term control of HC and CO emissions from heavy-duty trucks. The major provision of the recommended option was that HDGTs would be split along traditional class lines. Vehicles up to 14,000 lbs. gross vehicle weight (GVW) would be required to meet statutory standards (and thus have catalysts); all heavier gasoline vehicle engines would continue to meet non-catalyst standards. This approach attempted to capitalize on the transferability of light-duty truck (LDT) catalyst technology to the largest fraction of HDGTs (the lighter classes), while acknowledging the decreasing number of heavier HDGTs on which catalyst application would be most expensive (on account of the need to design increased survivability into catalyst systems used in the more extreme heavier truck environment). In short, emission reductions were hoped to be achieved in the most cost-effective fashion. The suggested implementation date for this strategy was the 1987-88 timeframe. Public comments on the staff paper were solicited and accepted up until May 6, 1983.

Prior to the May 6 close of comments, GM advanced an alternative approach at an April 13, 1983 meeting with EPA staff.[5] GM proposed that most* HDGTs under 10,000 lbs. GVW ("light heavy-duty vehicles") be required to meet emission standards similar to those required for LDTs, and be certified on the light-duty chassis dynamometer test procedure. Vehicles above 10,000 lbs. would continue to have their engines certified on EPA's heavy-duty engine test at non-catalyst emission levels. GM proposed that the scenario take effect in 1987.

Public comments received by May 6, 1983[5] addressed both the EPA and GM scenarios and are summarized by commenter below.

Chrysler

Chrysler cannot support the GM proposal, because of the proposed more stringent standards for LDTs below 6,000 lbs. GVW and proposed relaxation for LDTs between 8,500 and 10,000 lbs. GVW. Chrysler also opposes the creation of the light heavy-duty class, arguing it would require an additional test fleet for durability testing, thereby increasing costs.

Chrysler also claimed that EPA's engine dynamometer test is not representative of vehicles less than 10,000 lbs. GVW. Chrysler implied that another test would be better, but did not specify any particular test.

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* Some exemptions would be allowed on the basis of larger frontal area, etc.

Ford

Ford argued that catalysts are not feasible for all trucks, but may be feasible on trucks in the 8,500-14,000 lb category. Ford argued that catalyst standards should not be implemented before 1988, because of production leadtimes and the required 4-year leadtime provisions of the Clean Air Act.

Ford suggested that the heavy-duty class be split at 10,000 lbs., primarily because there are not many Class III trucks. Ford did not disagree, however, with EPA's concern about potential migration, should HDTs be split at 10,000 lbs. Indeed, if EPA does split HDTs at 14,000 lbs., Ford recommended specific vehicle types for exemption. These vehicles are those which see the most severe operation, and thus, would be those vehicles most difficult to equip with durable catalysts. Ford also agreed with GM that the LDT chassis test procedure would be appropriate for trucks under 10,000 lbs. GVW. Ford urged EPA to consider this testing alternative seriously.

With respect to catalyst feasibility and the feasibility of the 15.5 g/BHP-hr CO standard, Ford argued that temperatures above 1,600°F will cause thermal degradation of the catalyst. Catalyst protection systems are possible, but an overtemperature protection system of air injection cutoff at full load also cuts off CO control at its most significant mode. This trade-off between catalyst durability and CO control has not been characterized. Ford did claim, however, that their experience with LDT truck catalyst technology will be applicable to the 8,500-14,000 lb vehicle classes.

General Motors

General Motors argued that EPA's split-class approach was flawed. Specifically, EPA's approach does not make compliance any different for lighter HDTs because they would still be certified on the HDE test. GM argued that the test procedure itself will determine which technology is applied for emission control. In fact, much more than minor modifications to LDT systems would be required for usage on the heavy-duty test. GM argued that catalyst-equipped HDGEs will exhibit unacceptable durability and performance if certified on the transient engine test procedure. GM claimed that they were unable, based upon the lack of data, to define regulatory requirements based upon the engine dynamometer test procedure.

General Motors also took issue with EPA's rationale for splitting the classes. GM disagreed with EPA's conclusion that LDTs and lighter HDTs were not significantly different; GM argued that EPA has not proved that they are sufficiently similar to permit "easy" transfer of LDT control technology.

General Motors did agree that the heavier the total vehicle weight, the higher the catalyst temperatures were likely to be over the road. GM did not address the feasibility of catalyst protection systems.

Manufacturers of Emission Controls Association

The Manufacturers of Emission Controls Association (MECA) stated that EPA's split-class approach better balanced the needs and costs of controlling emissions from HDGTs. MECA further stated that if the operating environments of Classes IIB and III trucks are "...not significantly different both in terms of emission levels and thermal exposure from that experienced with vehicles currently equipped with catalysts, then it is expected that conventional light-duty truck catalyst technology could be applied with relatively minor modifications to trucks in those classes."

MECA also stated that several of its member companies are already working to develop catalysts for the Classes IIB and III trucks, and also to develop catalyst components that will withstand higher temperatures.

With respect to leadtimes, if LDT catalyst technology is readily transferable, MECA claims that adequate quantities of catalysts "...could be produced well within the timeframe needed to supply 1987 model year trucks." "If more heat resistant systems are needed for certain Class IIB and III vehicles, some additional development time will be necessary."

Natural Resources Defense Council

The Natural Resources Defense Council (NRDC) took strong exception to EPA's performance on the regulation of HC and CO emissions from HDTs. NRDC stated that EPA's split-class approach should mandate the entire 90 percent reduction in HC and CO emissions for the lighter class by 1985, instead of 1987-88 as EPA's staff paper suggested. NRDC supported the provision of a 1-year "safety valve" exemption for vehicles subjected to more severe operating conditions, if a need for such could be publicly demonstrated. NRDC also recommended that EPA seriously consider extending the lighter class upper weight limit from 14,000 to 20,000 lbs. GVW to prevent vehicle migration to higher weight classes.

NRDC also argued that the heavier classes should not be given a permanent exemption from the 90 percent reduction standards, even if such an exemption were technically justified for 1985 or 1986. NRDC claimed that a permanent exemption is not only detrimental to air quality, but also beyond EPA's legal authority.

Analysis of Comments

There are four basic questions concerning the issue of catalyst feasibility for HDEs: 1) can the catalyst-based standards be met at low mileage, 2) what type of catalyst system and hardware are needed to allow compliance, 3) what type of overtemperature protection is necessary for a catalyst operating at HDE conditions, and 4) how much leadtime is required for the development and production of such systems? These questions will be addressed in the following analysis, along with public comments to EPA's March 16, 1983 staff paper wherein EPA originally proposed the "split-class" approach.

Low-Mileage Feasibility of Catalyst-Based Standards

EPA's decision to defer catalyst-based standards beyond 1984 was not a technical one, but based primarily upon economic grounds and leadtime concerns. EPA concluded on January 21, 1980[1] that catalysts are feasible for use on HDGEs, and this analysis will not reiterate the detailed findings of that rulemaking. The associated Summary and Analysis of Comments document, published in December 1979,[9], discussed a limited test program which had been conducted by EPA during which the statutory standards had been achieved at low mileage on two test engines using catalysts. The conclusion of feasibility was, therefore, supported by actual testing conducted by EPA.

Since that time, EPA has collected data from three additional catalyst-equipped heavy-duty gasoline engines. (All five catalyst-equipped heavy-duty gasoline engines and their weighted cold/hot start transient test emissions are listed in Table 1-8.) In this more recent testing, EPA retrofited an IHC 404 CID engine with two three-way catalysts and two oxidation catalysts. A Ford 1985 prototype 7.5L HDE equipped with oxidation catalysts was also tested at the EPA facility. Finally, a GM 350-CID engine, with both a three-way and an oxidation catalyst, was tested at Southwest Research Institute. In addition, EPA notes that GM has tested a 1985 prototype 350-CID engine equipped with oxidation catalysts, and submitted that data to the Agency as part of the cooperative effort to determine the correlation between EPA and MVMA test cycles. All engines yielded emissions well below the 15.5 g/BHP-hr CO and 1.3 g/BHP-hr HC standards (see Table 1-8). Thus, laboratory testing of heavy-duty gasoline engines equipped with catalyst systems has established that these engines can comply with the statutory standards at low mileage.

Likely Emission Control Stategies

EPA believes that LDTs and most lighter HDTs are not subjected to significantly different operational environments, and that existing LDT catalyst technologies and strategies can be modified for use by HDEs (see below). The only significant difference affecting compliance technology between LDTs and the HDEs for which catalyst standards will apply is, as properly noted by GM, the larger engine exhaust mass flow induced by the heavy-duty transient engine test. This difference should only be manifest in the CO emissions. Necessary modifications to LDT control technology to permit compliance with the CO standard on the heavy-duty test include both changes to the air injection system and to the catalyst system itself.

Adding air to the catalyst ensures that there is sufficient oxygen to allow the oxidation of CO emissions. Air injection is most important, and potentially problematic, at full-power modes when the engine is operating under relatively richer mixtures. Most of the CO emissions generated on the transient test arise during these modes, and therefore high-power CO emission control is critical. Given the already high exhaust temperature at full power, substantial oxidation of the relatively abundant concentrations of CO could potentially raise catalyst temperatures to unacceptable levels. It has been argued by manufacturers that this fact may be the most difficult development problem to solve: any emission control system with sufficient air injection to permit CO compliance on the heavy-duty test, if that calibration is carried through to the in-use vehicle operating for sustained periods at full power, will create catalyst overtemperature problems in-use. In turn, catalyst durability could be severely impaired.

EPA's testing of the Ford 7.5L (see Table 1-8) examined the relationship between CO emissions and the injection of air to the catalyst. (Evaluations of catalyst temperatures were also made, and are discussed below with respect to catalyst protection systems.) Solenoid valves were installed in the engine's air injection system so that complete control of when air was being injected into the catalyst was achieved. Testing was conducted such that different amounts of air were added to the catalyst at wide open throttle (WOT). (WOT was defined as the condition when the manifold vacuum was equal to or less than 2 inches Hg, the point at which power enrichment was observed to substantially begin.) Figure 1-3 shows the observed trade-off between hot start CO emissions and the diverted air; Table 1-9 lists the hot start emission data. Even though WOT represents only a small amount of the total test time (4.5 percent), the CO emissions attributable to this fraction of operation are relatively high. By allowing more air to reach the catalyst, (i.e., air was injected a greater percentage of the time the engine was at WOT), there was a dramatic reduction in CO emissions. In fact, with full-time air injection, CO emissions were virtually eliminated. EPA's

Table 1-8

Catalyst Feasibility Testing
on the EPA Transient Test Cycle

Engine	Test Facility	Weighted Emissions (g/BHP-hr)* HC	CO	Comments
1979 GM 292	EPA	.58	12.25	Dual 50 g/ft^3 catalysts, 2:1 ratio of platinum palladium
1978 Production IHC 404	EPA	.28	8.98	Dual air pumps, 4-113 in^3 oxidation catalysts.
	EPA	.32	3.74	Extrapolated emissions with fourfold increase in air injection, four oxidation catalysts.
	EPA	.68	3.6	Dual-bed system and EGR, closed loop feedback carburetor, 2-151 in^3 TWC and 2-173 in^3 oxidation catalysts.
1975 GM 350	SwRI	.39	5.6	COC/TWC pelletized catalysts, closed-loop feedback carburetor.
1985 Prototype Ford 7.5L	EPA	.72	7.22	4-150 in^3 COC LDT catalysts in parallel, dual air pumps.
Prototype GM 350	GM	.53	5.62	2-260 in^3 COC new pelletized catalysts.

* EPA cycle based.

Table 1-9

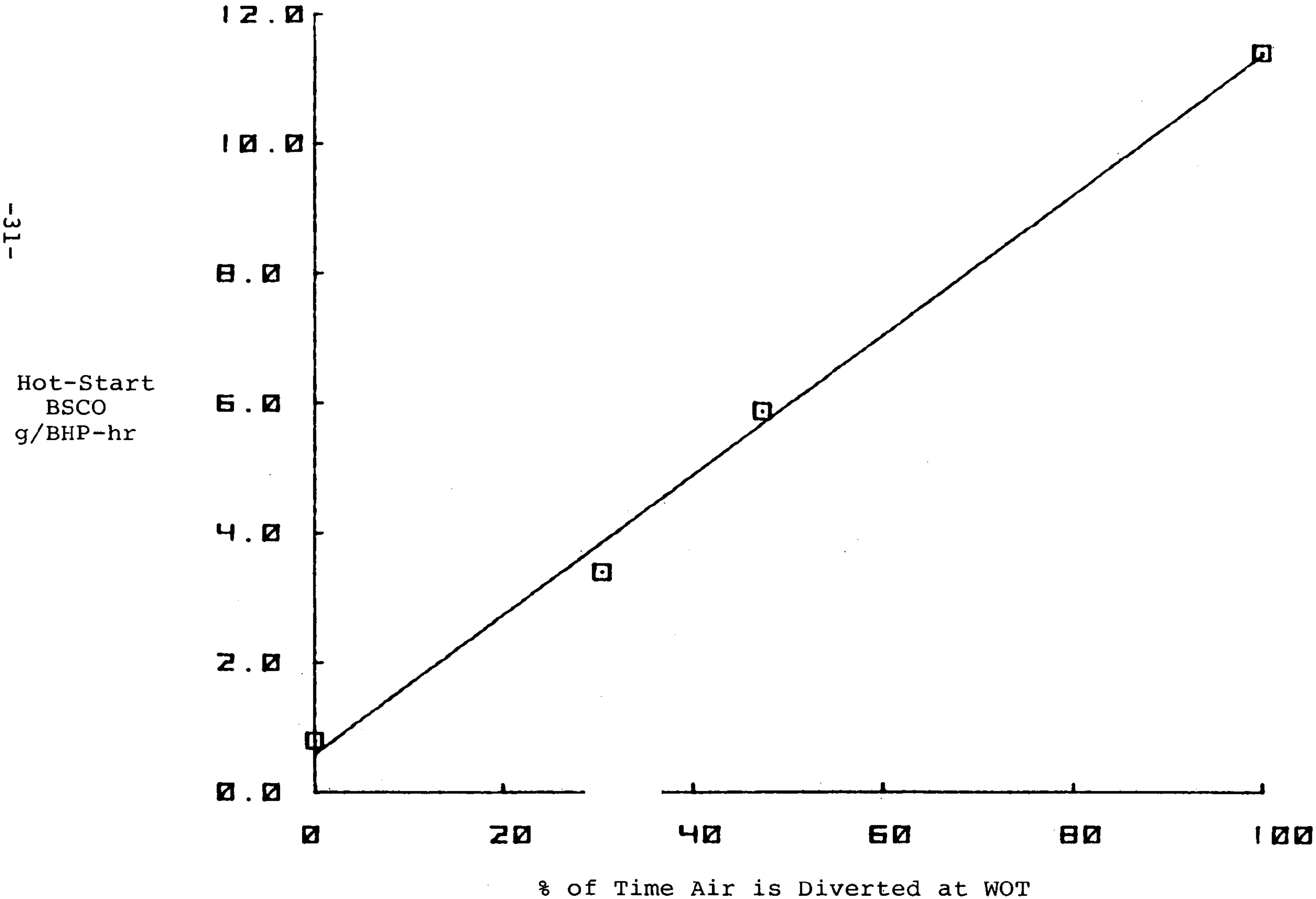
Hot Start CO Emissions As A Function Of Air Diversion at WOT

Air Dumping % Time at WOT	Air Dumping % Time of Complete Transient Test	CO Hot Start Emissions (g/BHP-hr)
0	0	.79
30.4	1.4	3.40
47.4	2.2	5.88
100.0	4.5	11.40

Note: Maximum catalyst bed temperature did not vary significantly between any of these tests, and never exceeded 1,600°F.

Figure 1-3

Hot-Start CO Emissions As a Function of Diverted Air From the Catalyst



testing also indicated that as much as 60 percent of the air can be diverted from the catalyst at WOT while still attaining a target CO emission level of 7.1 g/BHP-hr (EPA cycle based).* This ability to "by-pass" air, while still attaining required emission levels, has important implications for catalyst protection systems, as discussed later in this analysis. In summary, however, EPA sees no obstacle which would prevent modification of existing LDT or HDE air pump systems for usage with HD catalysts.

With respect to catalyst design, the two most important factors with respect to catalyst application to HDGEs are the noble metal loading and catalyst size. Location and geometry of the catalyst also affect its efficiency, as does substrate and noble metal material and density. Due to the higher mass flow of exhaust observed at full power on the HD test cycle, some changes may need to be made to existing LDT catalyst systems to maintain adequate CO oxidation efficiencies at these modes. In the worst case, larger, more heavily loaded catalysts may be needed. In other cases, changes to the exhaust and catalyst system geometry to increase gas residence time and eliminate "break through" at maximum exhaust flow will be necessary.

To evaluate how changing the geometry of the catalyst system affects its efficiency, EPA recently tested a Ford 7.5L engine with two catalyst configurations: 1) four catalysts in parallel, and 2) two sets of two catalysts in series. The brake specific carbon monoxide emissions for the parallel version were 59 percent lower than the emissions for the series version. By splitting the exhaust four ways instead of two, the exhaust flow velocity decreased, thereby increasing the residence time of the gas in the catalyst. This presumably allowed more time for the oxidation reaction to occur (eliminating "breakthrough"), and thus yielded lower overall CO emissions.

In summary, industry has several design options to maintain the required catalyst efficiency at full-power modes and to ensure that catalyst-equipped HDGEs meet the required CO target level. (EPA's earlier analysis[5] concluded that HC emissions will be reduced as a matter of course, and will be achieved primarily by assuring sufficiently prompt catalyst light-off on the cold start; EPA's recent data substantiated these earlier conclusions.) EPA believes that these

* Target CO Emission Level = 1/DF X 1/AQL X Emission Standard, where AQL = 1.283 (from above), and the multiplicative DF = 1.7 (from Reference 9).

modifications to air injection and catalyst systems are possible. Moreover, EPA believes that they represent the transfer of known emission control technology to different applications, and do not represent fundamental technological unknowns.

Catalyst Survivability

High operating temperatures create problems for maintaining catalyst efficiency over time:

> "The primary material used currently to support the noble metal catalyst in automotive converters is gamma alumina, in the form of either pellets or a washcoat on cordierite monoliths. At elevated temperatures, a phase change to alpha alumina begins which is accompanied by a reduction in the structural strength and surface area of the material. Active catalyst sites tend to diffuse and agglomerate as well as become inaccessible due to the loss of porosity; this process effectively reduces the number of sites available for catalysis and hence lowers the efficiency of conversion. Finally, the magnitude of the physical changes which occur in the alumina above the safe operating temperatures is a function of temperature, time of exposure, and the presence of certain ions which stabilize the gamma lattice."[9]

Due to the time and condition dependency of catalysts, there is no exact temperature above which a catalyst will suddenly fail. It is generally accepted that above 1,800°F, a catalyst will suffer serious damage. Operation between 1,600°F and 1,800°F is possible, but thermal degradation increases with time spent within that temperature range.

While none of the manufacturers in their comments disputed that the emissions from a heavy-duty engine can be reduced below the standards, they argued that catalysts are not feasible for all trucks. They argued that heavier trucks cause special problems for catalysts, such as the continually higher temperatures and greater mass flow of emissions from vehicles which spend a large percentage of operational time at full or very high power. They contended that these conditions seriously threaten the durability of currently available catalysts. EPA has since recognized the manufacturers' concerns of increased difficulty and cost of protecting catalysts under these circumstances, and thus EPA proposed the split-class approach as a solution.[7] In essence, the split-class approach allows more time for application of catalyst technology to worst case operational applications. The heaviest HDGVs (above 14,000 lbs. GVW), and also a limited number of lighter vehicles intended for the most severe applications, would continue for now to meet non-catalyst standards of 2.5/40.0. For these reasons, EPA believes that catalysts would not see extended service in severe operating temperatures if the "split-class" approach were adopted. This "split-class" approach is therefore the most important factor in assuring catalyst durability, presuming the use of existing catalyst materials and substrates.

Recent testing at EPA also included examination of the catalyst temperatures under various types of operation. The catalyst bed temperature of the Ford 7.5L heavy-duty engine never rose above 1,600°F during the transient test cycle for the parallel catalyst version; the version with series catalyst had maximum bed temperatures approximately 50°F higher in the catalysts closest to the exhaust manifold. A Ford 302 LDT engine that was tested on the HDE transient cycle by EPA had a maximum catalyst temperature of 1,640°F. Catalyst temperatures were also observed under conditions more severe than the transient test. Table 1-10 lists the maximum catalyst temperatures during WOT engine maps for two engines tested by EPA. Mapping conditions are extreme, and as expected, the catalyst temperatures are higher. Indeed, catalyst temperatures typically reach a maximum after the engine operates for sustained periods of time at WOT. Protection of the catalyst from too much oxidation of CO would be necessary at these conditions, if such conditions were expected to routinely occur in-use. (Note that these conditions are not seen on the transient test.) Again, however, EPA believes that the "split-class" approach would virtually eliminate sustained full-load operation from the vehicles required to use catalysts.

Aside from the elimination of the applications most detrimental to catalyst survivability, there are other strategies available to protect catalysts on HDGEs.

With increased air injection, the catalyst bed temperature increases as more oxidation occurs. One obvious means of protecting the catalyst at WOT is to divert the injected air from the catalyst mechanically, thus precluding increased oxidation. However, air injection cutoff at full load also may cut off CO control at the most significant moment. This creates an inherent trade-off between catalyst temperature and CO emissions.

This trade-off, however, is not significant enough to preclude compliance with the statutory CO standards. EPA bases this judgment on the test data discussed above, with which it was demonstrated that, for at least one engine, air injection could be completely diverted for up to 60 percent of the time spent at WOT on the transient test, and sufficiently low CO emission levels could still be maintained (see Figure 1-3 and

Table 1-10

Maximum Catalyst Temperature During WOT Engine Map

Engine	Catalyst Configuration	Temperature, °F
1980 GM 305-CID LDVE equipped with air/ oxidation catalyst/ EGR	One catalyst, stock location	1,734
"	4.5 feet downstream	1,660
"	6.5 feet downstream behind muffler	1,402
1985 Ford 7.5L HDE, equipped with air/ oxidation catalyst	4 catalysts in parallel 6 feet downstream	1,650

Table 1-9). This indicates to EPA that some form of the WOT air injection cutoff presently found on LDTs could be applied to HDGEs. In short, additional catalyst protection can be provided while still maintaining acceptable emissions levels.

Over-temperature protection systems, particularly for non-catalyst engines, have been discussed at some lenth by GM in earlier submissions. GM discussed several concepts, including one which would completely cut off full-power air injection after a certain amount of time (e.g., one minute) at sustained full power. GM noted that maximum temperatures require a certain amount of time to build up, and that such a system would protect the engine, and at the same time would be required very little in typical urban driving. GM's apparent concern, however, is that EPA may rule such a system to be a "defeat device" and forbid its use. EPA at this time cannot specifically approve or disapprove any system described to the Agency in a cursory or qualitative fashion; indeed, EPA's "split-class" approach should eliminate the need for such a system for now. However, past EPA policy with respect to the determination of defeat devices does not necessarily preclude the use of such a system. In general, EPA policy has been not to classify a technology as a defeat device if it can be demonstrated that such a device is essential for protecting the integrity of the engine, the integrity of the emission control system (e.g., catalysts), or the safety of the vehicle. In short, provided that such demonstrations can be made (for either catalyst or non-catalyst engines), additional flexibility could be available for protection from excessive temperatures, despite EPA's present belief that such protection is not currently necessary.

An additional means of providing temperature protection for the catalyst system has been discussed in earlier EPA analyses[9]--the ability to relocate that catalysts further downstream in the exhaust system. There are limitations to the degree of relocation protection available, primarily because HC emissions tend to increase dramatically as catalyst light-off time is sufficiently increased. However, a limited amount of temperature protection should certainly be available through relocation of the catalyst.

Finally, one additional measure providing major flexibility for certification will be available to the industry; EPA intends to retain the option of allowing a manufacturer to certify any vehicle of 10,000 lbs. GVW or less on the LDT chassis test procedure to LDT emission standards. Whether or not this option is exercised will be based upon the manufacturer's judgment of relative compliance costs; it is an option, however, which remains available.

In summary, EPA does not expect HDGE catalyst durability to represent a major problem. The "split-class" approach eliminates the most problematic applications. Several other techniques of catalyst and engine temperature protection are available. Air injection diversion at full load would be a technical derivative of systems already in production for LDVs and LDTs, and can be calibrated in such a way to both provide protection and achieve required emission levels. Catalyst relocation can also provide additional minor protection. Other protection systems could be used, if EPA were convinced that they were truly necessary for engine or catalyst survival.

Leadtime

This discussion focuses on the technical leadtime necessary to allow compliance with the "split-class" approach; legal issues regarding leadtime are specifically addressed in the Preamble of this rulemaking.

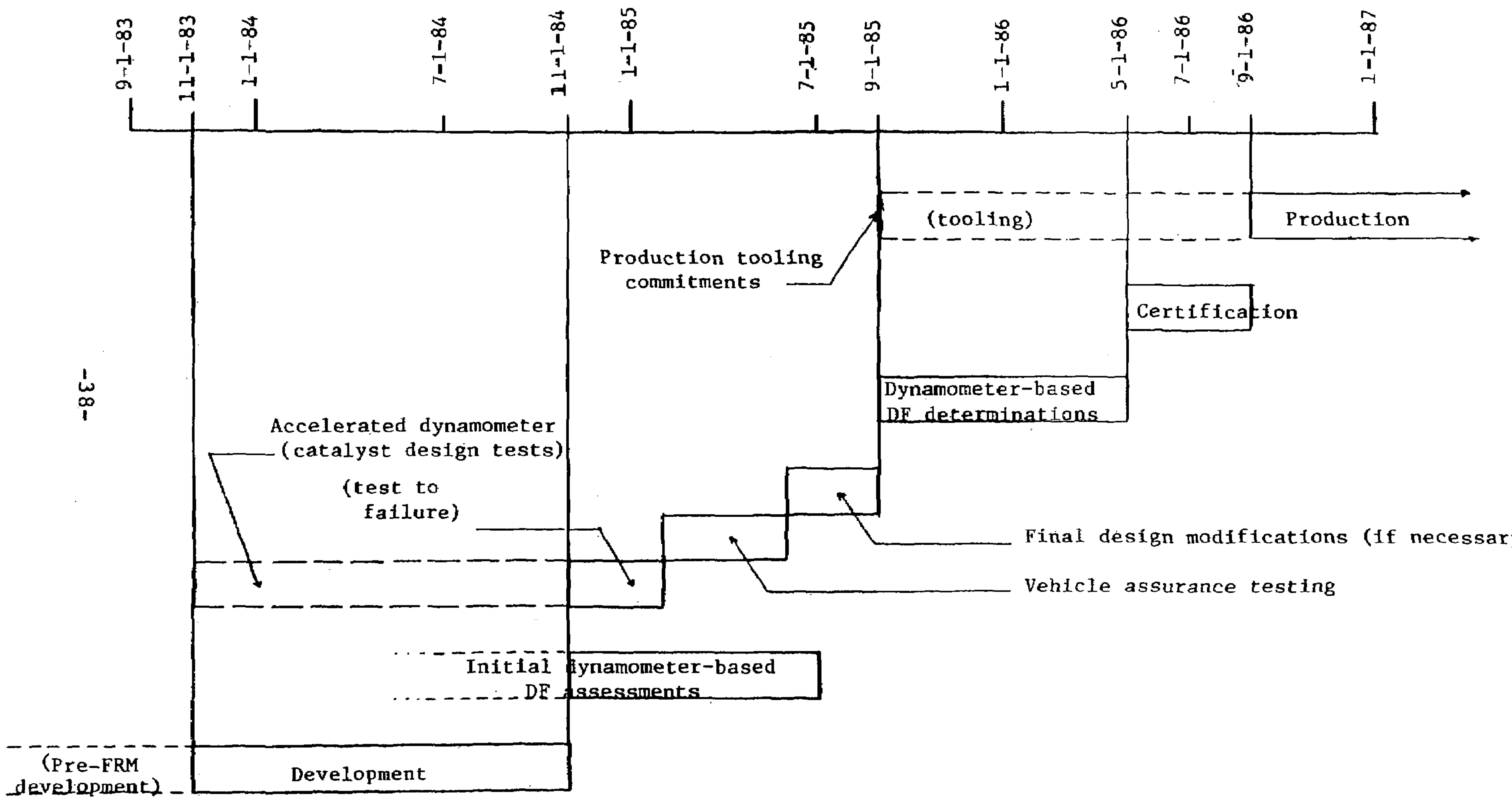
An outline of the technical ability of the manufacturers to comply with the statutory standards for HDGEs in Classes IIB and III applications is presented below. This general schedule (Figure 1-4) assumes a significant, although certainly attainable, compliance effort by the manufacturers. Of course, the specifics of the situation facing each manufacturer will determine exactly how much time is necessary for each phase of the effort and what sequence will be followed. The schedule in Figure 1-4 and the discussion below are intended to illustrate what needs to be known and what needs to be done; by allowing a reasonable amount of time for each phase, the feasibility of compliance is demonstrated.

The work can be viewed as phases of development, dynamometer and vehicle assurance testing, dynamometer-based DF determination, and certification. These phases are not necessarily sequential; in fact, there is certain to be a considerable amount of overlap. Assumptions that have been made in developing this schedule are noted where appropriate.

There are a few decisions that will be made, at least on a tentative basis, early in the development process. Under the split-class approach, where all worst case HDGEs (in terms of difficulty of catalyst application) are certified to non-catalyst standards, manufacturers are expected to divide their HDGEs into families on the bases of displacement and catalyst use. The families will be divided in such a way as to minimize disruption to the manufacturer's product line and inconvenience to the consumer. In addition, manufacturers will avoid situations that could result in competitive disparities; for example, a manufacturer would not want to use catalyst-equipped engines in vehicles that are in direct competition with similar vehicles without catalysts from

Figure 1-4

General Leadtime Schedule - MY87 HDGE Standards



a different manufacturer. In short, the manufacturers will substantially determine the structure of their 1987 product lines. The manufacturers will also make tentative judgments of likely DFs and the impact of the SEA requirement (effective in the 1986 model year), and thereby estimate target emission levels and the likely hardware and engine calibrations needed to begin development.

The most important phase, which EPA expects to last until October 1984, is for development work. It is clear from the history of this action and from manufacturer comments that preliminary development work has already been underway for some time, that a significant portion of the necessary work (i.e., reduction of engine-out emission levels) will have been performed in complying with the 1985 model year interim standards, and that early catalyst testing has been in progress since January 21, 1980. (For example, in comments submitted to EPA in April of 1982, GM provided a lengthy submission covering their heavy-duty catalyst development work to date.) EPA believes that the most significant problem to be solved during development is determining the catalyst configurations and engine calibrations that will be needed in order to demonstrate compliance on the HDGE transient test. Technically, this is a relatively straightforward engineering problem of applying known technology to new applications. As noted earlier in this chapter, the same generic technology will be used, with problems and engineering parameters similar to those encountered in applying catalysts to LDTs.

It is assumed that accelerated dynamometer testing, a fundamental part of engine and catalyst development, will occur during the development phase. Limited dynamometer-based DF assessments can also be conducted as part of the development phase in order to provide preliminary DFs. Following this, worst case durability assessments will be run to check for catastrophic failures. Such failures will become apparent in accelerated dynamometer testing, the last round of which is estimated by EPA to extend three months beyond actual development. (For mileage/service accumulation purposes, this testing may proceed 24 hours a day under automatic control. Thus the 1,500-hour half-life equivalent could be reached in as little as 2.4 months, assuming operation for six days per week. Note that GM's standard corporate durability test generally runs about 200 hours.) Approximate DF determinations based on dynamometer operation for the equivalent of the full-life (3,300 hours) could therefore be completed conservatively within eight months after the development phase is concluded.

After the worst case durability assessments are completed, EPA estimates that basic vehicle assurance testing could be done in about four months. This vehicle assurance testing will allow comparison of in-vehicle and dynamometer-based DFs, as well as assessment of the effectiveness of vehicle modifications (heat shields, catalyst location and mounting), system reaction to on-road phenomena (vibration), and overall effect on performance characteristics (driveability). Four months is adequate time to accumulate at least 25,000 miles of in-vehicle use, assuming 10 hours per day on the road for 5 days per week at an average speed of 30 mph. Vehicles in this program could be left in service; only the catalysts need to be switched periodically for inspection and oxidation efficiency testing on well-characterized engines. Assuming that the in-vehicle testing conditions are appropriately planned, four months should be more than enough time for identification of any vehicle-related flaws.

EPA assumed three months beyond the work described above for final design modifications to be implemented, if any are found to be necessary. All of this could be completed by September 1985, at which time production tooling commitments could be made. At this point a full year would remain before model year 1987 "Job 1" production must begin.

Although EPA considers the possibility to be remote, any fundamental problems that may arise should be evident after the completion of vehicle assurance testing and dynamometer-based preliminary DF assessments. Existing regulatory provisions would allow a manufacturer to petition EPA for relief in the event a serious risk of non-compliance appeared likely at this time. EPA does <u>not</u> believe, however, that such relief will be necessary on the basis of all information available at this writing.

The remaining 12 months before "Job 1" would be used for final dynamometer-based full-life DF determinations, which should take eight months or less, and certification. Under procedures applicable for 1985 and later model years, durability testing is not required to be a part of the formal certification process. If further changes to calibrations or hardware appear necessary, manufacturers would have the option of foregoing the eight month durability assessment, and merely use engineering judgment or use predetermined DFs for certification. Certification should then begin no later than May 1, 1986, and should take no longer than four months.

In summary, EPA estimates that compliance with the "split-class" approch is feasible for the 1987 model year.

Having outlined a general schedule that demonstrates the feasibility of compliance by model year 1987, EPA takes issue with the technical leadtime estimates supplied by Ford in its comments. Ford considerably overstated the amount of time necessary, and seemingly disregarded the considerable progress that has already been made. Where Ford has included three complete iterations of designing, building, and testing, EPA believes that at most two iterations will be required, particularly because of existing experience with LDT technology and because all worst case applications are excluded under the split-class approach. Ford also estimated the certification process to last for three years, which EPA finds unreasonable and unlikely.

On the other hand, the EPA leadtime estimates allow for little slack time. Despite EPA's judgment that legal authority exists for requiring compliance by model year 1986, the elimination of 12 months from the time estimates discussed above would preclude orderly development and make the risk of non-compliance for 1986 unacceptably high. With respect to 1987, EPA again stresses that all truly worst case HDGE applications, in terms of catalyst use, are excluded from the statutory standards by the split-class approach. In addition, catalyst-forcing emission standards for HDGEs were first promulgated in 1979. The interim standards for 1985-86 were never intended to defer catalyst standards permanently, but merely to provide short-term economic relief. Thus the Agency is confident that implementation of this approach by 1987 poses no insurmountable difficulties for the industry.

Conclusions

Statutory emission standards (1.1 g/BHP-hr HC and 14.4 g/BHP-hr CO based upon the MVMA cycle) for Classes IIB and III HDGEs should be promulgated for the 1987 model year. All heavier HDGEs should continue to meet non-catalyst standards, as would the small number (5 percent of total Classes IIB and III sales; see the "migration" issue, Section B.12, for further information) of lighter vehicles allowed to certify to non-catalyst standards on the basis of application.

References

1. "Gaseous Emission Regulations for 1984 and Later Model Year Heavy-Duty Engines," Federal Register 4136, Vol. 45, No. 14, Monday, January 21, 1983.

2. "Control of Air Pollution from New Motor Vehicles and New Motor Vehicle Engines; Revised Gaseous Emission Regulations for 1984 and Later Model Year Light-Duty Trucks and Heavy-Duty Engines," Federal Register 1642, Vol. 47, No. 8, Wednesday, January 13, 1982.

3. "Revised Gaseous Emission Regulations for 1984 and Later Model Year Heavy-Duty Engines and Light-Duty Trucks, Draft Regulatory Analysis," U.S. EPA, OANR, OMSAPC, ECTD, SDSB, Chapter II, September 1981.

4. Derived from comments submitted to EPA Public Docket No. A-81-20.

5. Derived from comments submitted to EPA Public Docket No. A-81-11.

6. Letter from Charles L. Gray, Jr. to Ford Motor Co., General Motors, Chrysler, and International Harvester, June 17, 1982, EPA Public Docket No. A-81-11.

7. "Issue Analysis - Final Heavy-Duty Engine HC and CO Standards," EPA Staff Report, March 1983, EPA Public Docket No. A-81-11.

8. Letter to commenters from Charles L. Gray, Jr., plus attachment, EPA Public Docket No. A-81-11, April 12, 1983.

9. Summary and Analysis of Comments to the NPRM, "Gaseous Emission Regulations for 1984 and Later Model Year Heavy-Duty Engines and Light-Duty Trucks," EPA, OANR, OMS, ECTD, SDSB, December 1979.

2. Issue: Useful Life

Summary of the Issue

This issue addresses the useful-life provisions that will apply to 1985 and later model year light-duty trucks (LDTs) and heavy-duty engines (HDEs). On January 12, 1983, EPA proposed a revised full-life useful-life approach and an alternative for comment (48 FR 1472). This section of the Summary and Analysis of Comments deals with the responses to the proposal and the selection of the appropriate useful-life approach in response to those comments.

Summary of the Comments

Introduction and Synopsis of Events

Useful life is the period, expressed in terms of time or vehicle miles, over which in-use vehicles/engines are required to demonstrate compliance with the applicable emission standards and the period for which they are required to warrant the emissions performance of their products. In 1979 and 1980 EPA promulgated regulations effective for 1984 and later model years that contained revised useful-life periods for LDTs and HDEs. Useful-life periods were changed from fixed intervals, representing periods representing somewhat less than half the service life of these vehicles/engines, to manufacturer-determined periods representing the full average period to engine retirement or rebuild.

EPA adopted these reguations over concern about the in-use performance of HDEs. Half-life regulations provided no incentive for manufacturers to be concerned about the long term emissions durability of their engines, since they had no liability for their performance past the half-life certification period. This problem could be only partly dealt with by establishment of lower emission standards. Lower standards would lower overall average emissions, but would not control departures from standards during the second half of a vehicle's life due to what are often know as "gross emitters". Gross emitters are those vehicles whose emissions are increased severalfold above normal due to the failure of emission control hardware. The in-use failure of emission control components could completely eliminate the improvements gained by lower standards. Indeed, indications are that as more advanced technology comes into use for control of emissions, the effects of in use failure becomes much more pronounced.

The goal, then, was to focus manufacturer efforts more toward in-use performance and durability of their engines and to insure that emission control systems were fully capable of lasting as long as the average engine. Full-life useful life provided that incentive, and gave EPA enforcement authority to deal with problems in the second half of a vehicle's life. It helped insure that durability would not be sacrificed in an effort to minimize costs. EPAs analysis of both the costs and air quality impacts of full-life useful life indicated that it was a beneficial and cost effective program.

Subsequent to that rulemaking, LDT and HDE manufacturers raised a number of issues relating to the practical problems of useful-life determinations and possible high costs of implementing a full-life useful-life approach. As a result, in April of 1981 EPA agreed to undertake a further study of the useful-life issue as a part of the President's program to provide regulatory relief to the automotive industry.

Comments received during the several comment periods and public hearings held during the course of this study led to the January 13 proposal. EPA offered two useful-life options in the NPRM: 1) a modified full-life requirement designed to address previously expressed concerns regarding full-life implementation, and 2) an extended half-life proposal with slightly more stringent emission standards to compensate as well as possible for the reduced stringency of half life. A formal durability testing program accompanied the half-life proposal, whereas the full-life allowed manufacturers to design their own programs. EPA's stated preference was for the modified full-life option; the half-life plan was provided only in the event of unforeseen problems with resolving full-life implementation issues.

The majority of the manufacturers favored a half-life useful-life definition; however, none found the EPA half-life proposal with the adjusted standards and extended durability testing to be acceptable. Although some manufacturers were willing to accept a longer useful-life period than presently exists none was willing to also accept the downward adjustment in the emission standards. Rather, they advocated a half-life useful life with no adjustment of the standards or durability testing requirement. However, acceptability of the half-life plan to EPA was fully contingent upon the adjusted standards to account for the decrease in the compliance period and upon extended durability testing requirements to increase the focus on emission control performance at higher mileages. The Agency felt that without those compensating qualifications, all of the environmental benefits of full life would be lost and such a change would effectively reduce the stringency of the standards. Since no commenters supported the provisions of the extended half-life approach as proposed by EPA, and since three commenters expressed a preference for modified full life, it is EPA's intention to retain the modified full-life approach. Therefore, the half-life plan will not be analyzed further, and the remainder of the analysis will concern itself only with comments pertinent to modified full life.

Before turning to analysis of specific comments it is important to reaffirm EPAs belief in the value of full-life useful life. EPA continues to hold to its original justification for this program as outlined above. Commenters have argued that EPA has not conclusively demonstrated that the in-use need exists to an extent which justifies taking action. While it is true that there is not a large body of data to demonstrate the need, EPA believes that the logic of the situation, along with what data is available argues strongly for the establishment of full-life useful life. Indeed, the very vigor of much of the opposition to extending manufacturers' responsibilities into the second half of the useful life argues in favor of the need for this action. If, as argued by manufacturers, the current durability of emission control components is adequate, then there is little risk involved in extending the useful life period. EPA believes that full-life useful life is needed to insure durable components and to provide an enforcement mechanism for in-use problems.

The comments have been divided into major and minor issues for convenience of analysis. Within the group of major issues, five significant areas have been identified. These include: 1) legal objections to EPA's modified full-life approach, 2) concerns related to the recall provisions, 3) the heavy-duty diesel engine subclasses, 4) the assigned useful-life periods, and 5) the air quality benefits associated with full life. In response to the last issue, an update of the environmental impact and cost effectiveness of useful life was undertaken which forms a part of the Regulatory Support Document. Briefly, since it will not be considered further here, this analysis shows that the adoption of EPA's modified full-life approach will produce up to a 1 percent improvement in air quality for ozone and CO in the mid-late 1990s. The analysis further shows that full life is very cost effective in comparison with other emission control strategies, projecting costs-effectiveness values of $206-484 per ton for HC and $12-24 per ton for CO. Interested parties are referred to Chapter 3 of the Support Document for further analysis in this area. Discussions of the other four main issues and several minor issues are presented below.

Legal Issues

Summary of the Comments

A large number of comments were received concerning EPA's legal authority for implementing the modified full-life approach. Comments fell in four major areas: 1) statutory authority for the full-life concept, 2) authority to establish different useful-life periods for purposes of certification, warranty and recall, 3) authority to group LDTs under 6,000 lbs. GVW with heavier LDTs and HDEs for the purposes of useful life, and 4) the appropriate period of recall liability for in-use vehicles and engines. These are discussed below.

Many comments were received that reiterated (either directly or by reference) claims made during the original rulemaking that EPA does not have the statutory authority to implement a full-life useful-life definition. A substantial number of commenters addressed the issue of Congressional intent with respect to a half-life versus a full-life definition, and cited portions of the legislative history of the Clean Air Act which they believed demonstrated that Congress intended that the half-life concept be retained for LDTs and HDEs, regardless of the actual language in the Act.

Second, comments were received on the modified full-life proposal which argued that the Act limits EPA to a single useful-life period for both certification under Section 202(a), and the in-use programs contained in Section 207 (warranty and recall). The commenters therefore concluded that EPA was precluded from establishing a useful-life period for warranty that was different from the useful-life period for certification and recall liability.

Third, Volkswagen of America (VW) stated that EPA had no statutory authority to create a separate LDT class for useful-life purposes for LDTs under 6,000 lbs. GVW. VW argued that the court decision which initially led to the creation of the LDT class by EPA (International Harvester vs. Ruckelshaus, 478 F. 2d 615, D.C. Circuit, 1973) applies only to the level of the emission standards, and does not extend to other regulatory requirements. Based on this premise, VW took the position that LDTs of less than 6,000 lbs. GVW may not be required to conform to a period longer than the statutory period for light-duty vehicles (LDVs) (i.e. 5 years/50,000 miles).

Fourth, several commenters expressed concern about the scope of their liability during a recall action. They believed that the full-life recall provisions would force them to "fix" all the vehicles/engines in the recalled group regardless of their age, mileage, or condition. The comments took the position that their recall liability should end with the assigned useful life and that they should not be responsible for any vehicle engine which has been rebuilt, regardless of mileage.

Analysis of Comments

The question of Congressional intent and EPA's statutory authority to adopt a full-life useful-life definition for LDTs and HDEs was also raised when the full-life concept was first proposed for these vehicle/engine classes. During those rulemakings, EPA prepared two separate Summary and Analysis of Comments documents on the full-life useful-life proposals, one each for LDTs and HDEs, and these are herein incorporated by reference.[1,2] These analyses concluded, as EPA still concludes, that the Clean Air Act as amended in 1977 provides the Administrator full authority to set the LDT and HDE useful life at any period of time and/or mileage longer than 5 years/50,000 miles if it was determined to be appropriate.

Manufacturers based their findings of Congressional intent for half life on the differences between the Senate version of the Clean Air Act Amendments of 1977 (S.252) and the final version that emerged from the conference committee and was later enacted. In the Senate version, the useful life for a "motorcycle or any other motor vehicle or motor vehicle engine would be a period of use the Administrator shall determine."[3] In the Amendments as they were enacted, however, "motor vehicle and motor vehicle engine" were removed from this clause and placed in a new clause which read that useful life for "any other" (than light duty) "motor vehicle or motor vehicle engine (other than motorcycles or motorcycle engines)" was to be a period of 5 years/50,000 miles "unless the Administrator determines that a period of use of greater duration or mileage is appropriate."[4] From this change in language, and the past use of the half-life concept for LDVs, LDTs, and HDEs, the commenters inferred that Congress intended EPA to retain the half-life concept for LDTs and HDEs.

First, it should be noted that EPA's authority to establish longer useful-life periods for LDTs and HDEs was established in 1970. The 1977 amendments did not address LDTs and HDEs directly, but were concerned with the problems of existing law created with respect to motorcycles. Thus, the 1977 amendments are not directly relevant to EPA's authority to set useful-life periods for LDTs and HDEs.

Moreover, in EPA's view, setting "any other motor vehicle or motor vehicle engine" apart from motorcycles and light-duty vehicles/engines simply retained a minimum 5 year/50,000 mile useful life for LDTs and HDEs and did not alter the Administrator's specific authority to set a period longer than 5 years/50,000 miles if it was determined to be appropriate. Congress was aware of the ongoing litigation between Harley Davidson and EPA on the issue of motorcycle useful life, and specifically provided statutory language to permit EPA to establish a useful life other than 5 years/50,000 miles for motorcycles in Section 202(d)(3).[5] Had this change not been made, and the Senate version retained, the 5 year/50,000 mile minimum would have been lost for LDTs and HDEs. Congress desired to keep that minimum, which led to the creation of Section 202(d)(2), which also contains EPA's authority to set a useful-life period longer than half-life. Therefore, reducing vehicle emission," but are emission-related, have to be warranted for only 2 years/24,000 miles under Subsection 207(a)(2).[6] Nevertheless, Section 202(a)(1) refers to "a period of use" for light-duty vehicle useful life; Congress evidently believed varying useful-life periods could exist notwithstanding the apparent reference to a single period. Since Congress was clearly aware of the possibilities involved and yet did not specifically prohibit the Administrator from making similar determinations for LDTs and HDEs, EPA concludes that authority exists under the general and specific authority mentioned above to allow the establishment of reduced warranty periods, and that the Administrator is not restricted to only one useful-life period for certification, warranty, and recall purposes.

It should be kept in mind that the reduced useful-life period for warranty is an attempt to be responsive to manufacturers' valid concerns with having to warrant LDTs and HDEs for their full useful lives, while not sacrificing the air quality and durability benefits of the earlier full-life useful-life requirement. EPA could have promulgated more stringent half-life standards with increased durability requirements, but opted instead for an approach that at least was favored by some manufacturers.

Finally, although EPA believes, for the reasons set forth above, that it would have authority to establish a different useful-life period for purposes of recall, that is not what the Agency has done. As discussed below, manufacturers in a recall will be required to repair non-conforming LDTs and HDEs regardless of age or mileage at the time of repair. EPA, as part of this rulemaking, has simply established a policy that LDTs and HDEs will not be tested for purposes of recall if they exceed 75 percent of their useful life. Indeed, even in the established LDV recall program EPA typically tests cars that are only two to three years old, notwithstanding a 5-year useful-life requirement. The recall policy established today for LDTs and HDEs is an attempt to be responsive to manufacturers' concerns that wornout or otherwise unrepresentative engines may inadvertently be selected for recall testing.

Turning to the issue raised by VW, EPA cannot accept VW's contention that the decision of the Court of Appeals in International Harvester v. Ruckelshaus was applicable only to compliance with emission standards. The decision of the Court led EPA to initiate a rulemaking which ultimately established the definition of a new LDT class and an entire set of emission regulations for new 1975 and later model year light-duty trucks. (85 CFR - Subpart C)(See 38 FR 21362, August 7, 1973). Since that time LDVs and LDTs have shared common requirements only when it was found to be technologically appropriate (e.g., test cycle). Beginning in 1979 the LDT class was expanded from 0-6,000 lbs. GVW to 0-8,500 lbs. GVW, and in subsequent regulatory actions EPA has used the general authority of Section 202(a)(1) to group the lighter weight LDTs with the heavier LDTs for purposes of complying with mandates of other portions of Section 202. In 1977, when Congress added language to the Act authorizing EPA to establish classes and categories for setting standards for HDEs, it specifically ratified EPA's approach for LDT regulations.[7]

Given that the Court of Appeals ordered EPA to remove light-duty trucks from the light-duty vehicle class in 1973, and that EPA has operated with a distinct set of LDT emission regulation and standards since 1975, EPA sees no merit in VW's argument. EPA believes that setting LDT useful life under Section 202(d)(2) is consistent with the past practice of establishing separate LDT provisions, and is a correct usage of Section 202(d)(2) since LDTs are neither LDVs nor motorcycles.

Finally, EPA recognizes the manufacturers' comments on recall liability. Current EPA policy is that all non-conforming vehicles/engines in a recalled family must be "repaired" regardless of their mileage, age, or condition at the time of repair. Recall evaluation testing will not be conducted past 75 percent of the assigned useful life; however, if a defect is discovered during such testing, it must be remedied for all non-conforming vehicles/engines in that family.

The Agency is now involved in litigation over this requirement (General Motors v. EPA, No. 80-1868, D.C. Circuit, 1980), so it is subject to possible revision based on the outcome. Final EPA response to these concerns is therefore not possible at this time.

Conclusion

The Act contains the necessary authority to establish the certification, recall, and warranty provisions embodied in the modified full-life useful-life approach. EPA has significantly revised these provisions in a way that should alleviate the manufacturers' most pressing concerns, while preserving the benefits of a full-life useful life-approach.

Recall Provisions

Summary of the Comments

A number of manufacturers have anticipated problems with the three-quarter-life recall provisions proposed by EPA as part of the modified full-life approach. The Engine Manufacturers Association (EMA) and several industry commenters stated that limiting recall evaluation testing to 75 percent of the assigned useful life would not fully address the problem of including rebuilt and wornout engines in a sample selected for recall testing. The commenters claimed that due to the variability found in actual engine service lives, it was quite possible that a substantial percentage of engines would be rebuilt before reaching the 75 percent of assigned useful-life cut-off point. For example, EMA estimated that 22-36 percent of heavy-duty diesel engines would have been rebuilt and an additional unspecified percentage would be in need of rebuild. Commenters believed that the difficulties in screening such engines would add to the cost of recall testing and might lead EPA to "cut corners" by basing a recall on too small a sample or by including marginal engines in the test program.

The commenters also expressed several other concerns related to the recall program. Mack Trucks, Inc. expressed concern over the potential impact of the 40 percent Acceptable Quality level (AQL) of EPA's Selective Enforcement Audit program on the recall evaluation program, stating that as a result of the 40 percent AQL, there is a near 40 percent chance that an engine taken randomly for recall evaluation may have been above the standard when it left the production line.

Mack Trucks also stated that laboratory-to-laboratory variability must be considered in any recall evaluations, since results of the EPA/EMA round-robin test program indicated that up to a 25 percent variation existed between certain test facilities.

Mack also requested that EPA provide a three model year "grace period" from recall liability for newly introduced engine lines. Mack was concerned that even the best engineering practices may not allow them to predict their in-use emissions deterioration accurately for these new engine lines, and that their in-use engines may exceed the emission standards as a result.

Some manufacturers wanted EPA to limit recall liability to a select list of emission control components only, although the American Trucking Association (ATA) doubted that EPA had the authority to do so.

Analysis of the Comments

The problem of screening vehicles/engines for improper maintenance, abuse, rebuild, wearout, etc., prior to inclusion in a recall sample is not new. Such screening is now successfully conducted in the LDV and LDT recall programs, and EPA expects to use a similar approach under full life for LDTs and in the recall program currently being developed for HDEs. The manufacturers are given several opportunities for participation in the recall program. Under the current program manufacturers are given the opportunity to comment or otherwise respond to the Maintenance/Use Criteria questionaire which serves as the first level of screening for prospective vehicles. The second level of screening is a physical inspection of those prospective vehicles/engines which pass the first level of screening. At this point, the manufacturers are invited to be present at the inspection and to provide input to EPA as to why a given vehicle may or may not be representative for recall evaluation testing. Should any disagreement arise, the current recall program allows manufacturers a full opportunity to challenge vehicle selection. And, of course, the manufacturers are involved in the recall provisions as discussed in Subpart S of 40 CFR Part 85. Finally, in the unlikely event that disagreements with the recall sample remain, manufacturers are given an opportunity, in an adjudicatory hearing, to contest EPA's determination that the class is in non-conformity. The results of that hearing are, of course, judicially appealable.

The above procedures involving recall screening ensure that the manufacturers are indeed involved in the current recall screening process, and EPA fully expects that such involvement will continue in the full-life LDT program and the developing HDE recall program. EPA expects considerable dialogue with the industry on the implementation details of these new programs, and in fact some preliminary discussions have been held. EPA presented a brief synopsis of the current LDV/LDT recall program at the Useful-Life Workshop on February 18, 1983, and a subsequent meeting was held between EPA and EMA representatives on June 2, 1983.[8]

In any event, EPA and the industry are in agreement on the need to develop procedures and implementation approaches for minimizing the possibility that a rebuilt or wornout engine might be included in a recall evaluation sample. Since few LDTs are rebuilt and no HDE recall program currently exists, EPA believes that the full-life useful-life requirement can be implemented now, and the details for implementing the provisions of the recall program for LDTs and HDEs can be refined in the future, through discussions between EPA and the industry.

Although EPA can understand how Mack might make a connection between the 40 percent AQL and its impact on the recall program, there simply is none. SEA and recall are two distinct EPA programs, addressing compliance on the assembly line and in use, respectively. The AQL in SEA testing was not established at 40 percent to condone nonconformance, but was set at that level in recognition of manufacturing practicalities and economic and other negative impacts of an SEA failure (i.e., lost production, lost wages while a fix for the problem is implemented, etc.). In fact, any vehicle/engine which fails during an SEA must be fixed before it can be sold.

It is still the Agency's desire and should also be the manufacturers' goal, that every vehicle/engine produced meets the emission standards when produced. Therefore, EPA does not feel constrained by the 40 percent figure for the recall program, since the goals of the two programs are different. EPA also notes that the LDV SEA program includes a 40 percent AQL and the LDV recall program has not suffered as a result.

In response to Mack's comments concerning laboratory-to-laboratory variability and also as a partial response to Mack's concern over the impact of the 40 percent AQL, it should be noted that the lack of rigidly defined procedures for recall evaluation and for determining that a substantial number of vehicles/engines are in nonconformity, provides EPA some flexibility for accounting for the impact of such factors. EPA expects to continue judicious use of this flexibility in the future to account for factors such as these.

EPA cannot agree to Mack's request for a 3-year grace period from recall liability for new engine lines, while the manufacurer gathers in-use data on the performance of its new engines. Manufacturers do not introduce new engine lines to the marketplace without extensive durability and assurance testing both on engine dynamometers and in actual vehicles before production begins. Given this practice, and EPA's provisions which allow manufacturers to determine their deterioration factors by any means they deem appropriate, the manufacturers should be able to utilize the results of such durability and assurance testing to determine a reasonably accurate deterioration factor. To account for unforeseen problems in use, the manufacturer can always build a cushion into the certification deterioration factor or decrease low-mileage targets and thereby minimize in-use noncompliance risk. Manufacturers cannot be spared the liability of not complying with the emission standards in use. This is a central and important part of the mobile source control program; it ensures that manufacturers build engine/vehicles that perform well in use.

Regarding the idea of limiting recall liability to a specific list of emission control components, EPA cannot accept the manufacturers' position. The industry has argued that emission-related components (i.e., those that affect emissions, but are not specifically designed for emission control--fuel injection systems, for example) should be excluded from recall liability becuase they will be kept in good repair to avoid degradation in performance and fuel economy. This may be true, and, if so, defects uncovered in emission-related components would be rare and should pose no problem to the manufacturers. Conversely, recall evaluation testing may find that there are significant problems with emission-related components, and a recall program would assure correction of these problems.

Publishing a list of select emission control components would preclude the possibility of correcting such problems should they be uncovered. Finally, in the recall provision of the Act, Congress did not limit recalls to non-conformities caused by certain components, but rather required remedial action when a class of vehicles fails for any reason to conform to the applicable emission standards.

Conclusions

EPA will work closely with the LDT and HDE manufacturers to ensure that the new recall programs are implemented in an equitable and reasonable manner, and that manufacturers' concerns over wornout and rebuilt engines are properly addressed. These implementation provisions will be developed with public involvement, and will be modified in the future as experience dictates. There is every reason to believe that these new recall programs can work as smoothly as the current LDV and LDT programs. EPA concludes that no additional recall provisions are required at this time to implement the modified full-life useful-life approach for 1985.

Heavy-Duty Diesel Engine Subclasses

Summary of the Comments

EMA and several manufacturers did not agree with EPA's approach of subdividing the heavy-duty diesel engine (HDDE) class on the basis of gross vehicle weight (GVW). In the proposal, EPA subdivided the HDDE class into three distinct subclasses based on a range of GVWs and then assigned useful-life periods to each subclass. Under the EPA approach, an engine's assigned useful-life period would then be derived from the GVW of the vehicle in which the engine was installed. EMA commented that this approach was flawed because a given engine line might be sold for use in applications which encompassed more than one HDDE subclass. EMA also did not like the nomenclature which EPA used to identify its three HDDE subclasses (i.e., medium, light heavy, and heavy heavy).

As an alternative approach, EMA suggested splitting the HDDE class into three subclasses based on the primary intended service application for which the engine was designed and sold. These three subclasses would be called light heavy-duty diesel engines (LHDDEs), medium heavy-duty diesel engines (MHDDEs), and heavy heavy-duty diesel engines (HHDDEs). The LHDDE subclass would cover applications such as motor homes, multi-stop vans, large utility vehicles, pickup trucks, and delivery vans. The MHDDE subclass would cover engines that were designed for short haul or intracity operation such as van trucks, stake trucks, single axle tractor/trailers combinations, and school buses. The HHDDE subclass would primarily entail engines designed for full-load, long haul intercity operation, such as those used in over-the-road tractor/trailer trucks and intercity commercial buses. EMA further recommended that EPA review each manufacturer's primary service category designation to ensure that engines were properly classified for regulatory purposes.

Virtually all of the HDDE manufacturers concurred with EMA's comments. However, Daimler-Benz and ATA suggested engine horsepower as another plausible approach since it would also allow the manufacturers to characterize the engines in the manner in which they were normally used.

Analysis of Comments

The HDDE classification approach suggested by EMA has considerable merit. Basing the HDDE subclasses on primary intended service applications is preferable to the GVW-based approach by EPA, because it avoids two potential problems of the GVW-based approach. First, it avoids the potential design, certification, and recall complications which arise if an engine model would be used in more than one of the GVW-based subclasses proposed by EPA. This problem is avoided simply because GVW is removed as a useful-life determinant. Second, it avoids the potential problems associated with atypical applications within the GVW-based subclasses proposed by EPA. For example, even though garbage trucks fall in GVW Classes VII and VIII (HHDDE under the EPA GVW-based approach) their engine requirements and vehicle usage patterns are not typical of most Class VII and VIII vehicles. Under EPA's proposed approach these engines would have been assigned the same useful-life period as over-the-road trucks, which probably would not be appropriate. The primary intended service application approach avoids this GVW-based complication, and recognizes that a typical MHDDE may be efficient in this application, and would have a useful life typical of MHDDEs, not HHDDEs.

The HDDE classification approach suggested by EMA is preferable to that proposed by EPA. For those engines which do not readily fall into either the light, medium, or heavy heavy-duty subclass, EPA is retaining the provisions which allow the manufacturer to petition the Administrator for a different useful-life period.

At this time, EPA foresees no need to review the manufacturers' primary intended service determinations as suggested by EMA, and does not desire to establish the need for additional approvals during certification. EPA believes that a labeling requirement could be used to assure that engines are not misclassified. Under this approach, manufacturers will be required to label HDDEs as to the subclass for which they are certified. The label will also include alternative assigned useful-life periods, if applicable, as described above. Market forces should then help ensure proper engine classification by the manufacturer, and selection of the appropriate engine by the purchaser. Although this approach should guard against abuses, EPA retains the right to challenge any manufacturer's practice in determination of subclasses should misclassifications occur.

The horsepower-based approach proposed by two commenters may also be plausible, because there is generally a relationship between engine horsepower and other parameters such as the load factor which could in turn adequately delineate an engine's application. However, this approach is not preferable to that proposed by EMA because no body of data is readily available which could be used to develop an appropriate relationship between engine horsepower and average useful life.

Conclusions

The HDDE class will be split into three subclasses on the basis of primary intended service application, as suggested by EMA. Each engine will be labeled with the subclass for which it is certified. The provision allowing a manufacturer to request a different useful-life value under special conditions will also be retained. However, these values will have to be printed on the label.

Assigned Useful-Life Periods

Summary of the Comments

All of the manufacturers claimed that one or more of EPA's proposed assigned useful-life periods (period to engine retirement or rebuild) as too long. Since the comments pertaining to the various assigned useful-life periods are fairly specific and detailed, they will be grouped by vehicle/engine class and each will be prefaced by EPA's rationale for establishing the useful-life value which was originally proposed. The development of the assigned useful-life periods is more fully documented in an EPA memorandum which was released concurrent with the proposal.[13]

a. Light-Duty Trucks

EPA's proposed assigned useful life of 12 years/130,000 miles was based on an average of the following data:

Engine rebuild surveys

Survey Data Research (SDR) "maximum likelihood"	171,000 miles

SDR "median ranks"	141,000 miles
Scrappage data	
DOE	124,000 miles
Michigan Technological University (MTU)	120,000 miles
Engineering Estimate	
Myers, SAE 750128	100,000 miles
Average	131,200 miles

The two Survey Data Research (SDR) survey numbers were based on the same set of survey data, aggregated and analyzed in two different ways. Ford Motor Company stated that this was inappropriate because if the data set forming the basis for the two analyses were biased in any way, the effect of the error would be doubled (since it would constitute 40 percent of the average, rather than 20 percent). Ford believed that the data were biased, because the two projected engine rebuild mileages were higher than the mileage at which the average vehicle would be scrappped by roughly 20,000 and 50,000 miles, respectively. Ford claimed that this was contrary to the common sense conclusion that the miles to rebuild should be less than the mileage at the vehicle scrappage point.

EMA and GM stated that the use of scrappage data in developing useful-life mileage values for LDTs and HDEs was inappropriate because the data included engines that had been rebuilt, therefore raising the average scrappage point mileage. They also asserted that use of scrappage-rate data represented a departure from the Agency's original regulatory intent of basing useful life on mileage to engine rebuild. GM carried this argument one step further, saying that useful-life periods should be based on the need for rebuild rather than on "owner action," (i.e., actually having the engine rebuilt). GM did not offer any suggestions, however, as to exactly how this determination was to be made, other than to say that they felt EPA's previous effort to provide objective end-of-life indicators for screening wornout engines out of recall samples (the rebuild criteria in 40 CFR §86.084-21) was "unworkable" in terms of accomplishing the stated objective.

VW argued that the data used by EPA to develop the LDT assigned useful life did not include the smaller 4-cylinder pickups that have been introduced in the last few years and which they felt are not designed for a useful life of 130,000 miles.

b. Heavy-Duty Gasoline Engines

EPA averaged the following data in proposing an assigned useful life of 120,000 miles for HDGEs:

Rebuild surverys	
SDR "maximum likelihood"	134,000 miles
SDR "median ranks"	124,000 miles
Fleet Maintenance and Specifying magazine[9]	100,000 miles
Scrappage rate data	
DOE	129,000 miles
MTU	114,000 miles
Average	120,200 miles

Ford, GM, and EMA all felt that the useful life for HDGEs should be 100,000 miles or less. This contention is based on the arguments mentioned above for LDTs regarding scrappage data versus rebuild data and also on their belief in the possibility that the SDR survey data overstated mileage to rebuild. EMA suggested the inclusion of data from a rebuild survey conducted by the ATA and also engineering estimates from a draft study done under EPA contract by Arthur D. Little, Inc.[10,11]

c. Heavy-Duty Diesel Engines

In the proposal, EPA split the HDDE class into three subclasses based on GVW, and proposed useful-life periods based on the general design and usage characteristics of each. The "medium-duty diesel" subclass, all HDDEs in vehicles less than 19,500 lbs. GVW (Classes IIB-V), represented a relatively new diesel application in a field heretofore dominated by gasoline engines and there were few data available regarding average service life. However, EPA reasoned that since these engines introduced as a replacement for HDGEs, they should last as long as the gasoline engines they were designed to replace in order to be competitive, and so a similar useful-life period of 120,000 miles was proposed.

The second subclass proposed, "light heavy diesel," (19,501-26,000 lbs. GVW - Class VI) had a useful-life period of 200,000 miles, which was determined by averaging the following data:

Rebuild Surveys	
SDR (Class VI engines)	203,000 miles
Fleet Maintenance and Specifying Magazine	229,000 miles*
Engineering Estimate	
Myers	162,500 miles**
Average	198,167 miles

* Average of values for sleeved and non-sleeved bus engines.
** Midpoint of range.

The third subclass was called heavy heavy-duty diesel (GVW above 26,000 lbs. - Classes VII-VIII). Since the data available indicated that virtually all heavy heavy-duty diesel engines were rebuilt, the proposed useful-life value was based on an average of two rebuild surveys:

SDR	267,000 miles
Fleet Maintenance and Specifying Magazine	281,000 miles
Average	274,000 miles

Since most manufacturers supported the EMA alternative HDDE classification scheme discussed earlier, their comments concerned both the methodology used by EPA to develop the proposed useful-life values and EPA's methodology and its results as they applied to the HDDE subclasses suggested by EMA. Since EPA has accepted the EMA classification system, the summary and analysis of comments for HDDEs will focus on those comments pertaining to EPA's methodology for estimating useful-life periods and the relationship between the assigned useful-life periods proposed by EPA and the EMA HDDE subclasses.

For the sake of clarity, further references to the HDDE subclasses will use the EMA terminology (LHDDE, MHDDE, and HHDDE). When the subclasses proposed by EPA are mentioned, their full names with be used (medium-duty diesel, light heavy-duty diesel, heavy heavy-duty diesel).

Having presented the necessary preliminary information, we turn now to the comments. First, no significant comments were received on EPA's proposal that the medium-duty diesel assigned useful-life period should be the same as that used for HDGEs. Ford agreed with this approach.

For the next subclass, EMA disagreed with EPA's use of the vocational groupings in the Fleet survey as being representative of LHDDE and MHDDE usage for establishing useful-life periods. The Fleet survey aggregated the data on the basis of vocational application (e.g., bus fleet, utility) as well as on the basis of some significant engine design characteristics (sleeved versus non-sleeved engines). EMA suggested that since most MHDDEs are non-sleeved, the MHDDE assigned useful-life period should be based on the Fleet rebuild mileage for non-sleeved engines (175,000) rather than on vocational categories.

EMA and Ford suggested that the SDR survey rebuild mileage for Class VI engines used in the EPA calculation of the useful-life period proposed for light heavy-duty diesels was inappropriate for use in calculating the useful-life for MHDDEs under the EMA classification system. Even though the light-heavy-duty subclass proposed by EPA and the MHDDE subclass proposed by EMA are quite similar, it was thought that the SDR sample for Class VI engines likely included a number of premium HHDDEs which would raise the average rebuild mileage. Thus, EMA and Ford believed that the MHDDE useful life should be less than that determined for EPA's GVW-based light heavy-duty diesel subclass.

It was also suggested that data from the ATA maintenance survey and from the draft study by Arthur D. Little be added to the data used for calculating the average useful-life periods. Given this information, EMA, Ford and GM felt that the MHDDE average full-life value should be 170,000 miles, based on the change in methodology. Caterpillar felt the MHDDE figure should be 150,000 miles, based on an average value of different applications of their 3208 model.

There was not significant disagreement on the assigned useful-life period of 275,000 miles EPA proposed for heavy heavy-duty diesel engines, although several commenters noted that operation of Class VII trucks is not typical of that of Class VIII trucks. In their view, the 275,000 miles was far more representative of Class VIII operation than Class VII operation.

EMA also suggested that the EPA assigned useful-life year values were not equivalent to the mileage values for the various classes/subclasses. They argued that equivalency should be maintained.

Analysis of the Comments

a. Light-Duty Trucks

EPA accepts the Ford comment regarding the use of two different numbers resulting from alternative analyses of the same set of data in the SDR survey. EPA intended to use the SDR data as a rebuild mileage survey, and to let the scrappage rate data serve for high-mileage non-rebuilds. Since the SDR "maximum likelihood" figure in question includes non-rebuilt engines in determining average lifetime mileages, it would be inappropriate to include it as a rebuild figure. Therefore, EPA has dropped the SDR "maximum likelihood" value from the averaging total and has used only the "median ranks" value, which is limited to rebuilt engines.

Regarding the comments on including scrappage data in the useful-life calculation, EPA believes the manufacturers have misinterpreted the Agency's intent regarding what constitutes useful life. In the original full-life useful-life regulations, useful life was defined as "the average period of use up to engine retirement or rebuild, whichever occurs first" (emphasis added).[12] Under the modified full-life definition it is the Agency's intent to retain this concept. Thus, it is not EPA's intent that useful life should be only mileage to rebuild when establishing the assigned useful-life values in the modified full-life plan but rather that it should also consider vehicle scrappage. Moreover, both "rebuild" and "retirement" (scrappage) can be described as "owner actions" and there is no mention of "need" for a rebuild in the above definition. Available data indicate that the average LDT is far more likely to be scrapped than to be rebuilt. An analysis of the SDR survey data indicate that only about 12 percent of all LDTs are ever rebuilt.[13] Thus, for 88 percent of the vehicles in question, useful life is the mileage to "retirement" rather than the mileage to rebuild, and exclusion of scrappage data would overlook a significant body of data in the calculation of average useful life.

While EPA acknowledges the point made by EMA and GM that there may be some bias introduced into the scrappage rate data by the presence of high mileage rebuilt engines, the percentage of rebuilds (about 12 percent) is not large enough to have a significant effect. Also, it should be recognized that there are also biases in the other direction. Scrappage totals include many low-mileage wrecks, for example, which tend to lower the average. A major driveline failure may also result in scrappage of a vehicle with additional miles remaining in the engine because retirement and replacement would be more cost-effective than repair. None of the available data on average useful-life periods are without some drawbacks. With the exception of HHDDEs where virtually every engine is rebuilt at least once, neither rebuild data nor scrappage data is adequate in and of itself to unequivocally establish useful-life periods. Therefore, in light of these unavoidable uncertainties, EPA has averaged data from a wide variety of sources to minimize the effect of the deficiencies in the data bases. These deficiencies were judged to be minor, and in some cases offsetting, thus allowing EPA to derive a representative useful-life value.

While VW is correct that the data used in deriving the LDT useful-life value do not include the newer, smaller light-duty trucks, EPA sees no reason why the service lives of these latter vehicles should differ significantly from those of the standard size LDTs. While the lighter LDTs are powered by smaller, less powerful engines, usually of 4 cylinders, and operate at somewhat higher engine revolutions than conventional LDTs, the trucks themselves are also lighter in weight and have less payload and frontal area than their standard-size counterparts. Few if any of these small pickups are likely to be loaded to maximum capacity with any degree of regularity and, as VW's comments indicated, the vast majority will in fact be used for personal transportation, as are many standard LDTs. EPA, therefore, concludes that there is no need for a shorter assigned useful life for these vehicles. Since neither VW nor any of the other commenters submitted any data to substantiate the need for a shorter useful life for the smaller LDTs, EPA will continue a common useful-life period for all LDTs. LDT manufacturers also have the option of requesting an alternative useful-life value in cases where the assigned useful-life value is significantly unrepresentative of the useful life for a particular engine family.

Therefore, the only change necessary to the LDT assigned useful-life period calculation is to drop the SDR maximum likelihood rebuild number, and reaverage the remaining four sources. An average of the four sources remaining yields a figure of 121,000 miles, so EPA will reduce the assigned useful life for LDTs from 130,000 miles to 120,000 miles.

b. Heavy-Duty Gasoline Engines (HDGEs)

EPA rejects the arguments advanced by EMA and others regarding the exclusion of scrappage-rate data in the HDE useful-life calculation for the same basic reasons outlined above in the LDT discussion. The SDR survey data indicate that only 28 percent of the HDGEs are rebuilt or replaced, so again, for the vast majority of HDGEs, useful life is the mileage to retirement.

Although the above-mentioned Ford comment regarding SDR survey data was made in reference to LDTs, the same general considerations hold for HDGEs as well. The two HDGE rebuild mileages from the SDR survey are not as disparate as the LDT figures. However, if the SDR data are to be representative of engine rebuild data in the HDGE average useful-life calculation, the "maximum likelihood" value should be dropped, since it includes non-rebuilt engines.

EPA will also include rebuild data from the American Trucking Association survey and estimates from the Arthur D. Little draft truck usage study as suggested by EMA. Although the contract under which the latter study was done was terminated prior to completion, the useful-life estimates in the report are reasonably consistent with other engineering estimates, and EPA has no objection to inclusion of the A. D. Little figures in the useful-life calculation. As shown below, an average of the two scrappage rate values, the three rebuild survey mileages, and the two engineering estimates results in a useful-life period of about 108,000 miles. Therefore, EPA will assign a value of 110,000 miles for HDGEs, rather than the proposed value of 120,000 miles, based on the following calculation:

Scrappage Rate Surveys:	
Michigan Technological University	114,000
DOE	129,000
Rebuild Surveys:	
SDR	124,000
Fleet	100,000
ATA	89,000*
Engineering Estimates:	
Little	100,000
Meyers	100,000
Average	108,000

* Sales-weighted average of trucks under 20,000 lbs. GVW (73 percent of sales) and of trucks over 20,000 lbs. GVW (27 percent of sales). These projected sales percentages were multiplied by ATA mean survey mileages of 91,447 and 82,450 miles, respectively. If the modal or median values are used, the sales-weighted rebuild mileages are 94,600 and 90,950 miles, respectively.

c. Heavy-Duty Diesel Engines

As in the Summary of the Comments, the EMA subclass designations will be used throughout this section of the analysis to avoid the confusion that would result from use of both EPA and EMA terminology. The analysis will also be oriented toward the EMA subclasses, since EPA is adopting them over the subclasses as defined in the proposal. EPA agrees with EMA that the Fleet vocational based rebuild figures used in the MHDDE and LHDDE useful-life calculation may have deficiencies. In any event, as stated in the above-mentioned support memorandum concerning useful-life derivation, the LHDDE subclass was assigned the same useful-life period as HDGEs, on the judgment that LHDDEs should last about as long as the HDGEs they were designed to replace.[14] The Ford comments and a request by EMA to certify these engines to the HDGE useful life provide additional support for this position.[15,16] Since the HDGE useful-life period is based in part on the use of scrappage-rate data, the EMA objection to its use also carries over to the LHDDE subclass value. There are relatively few data on the subject for LHDDEs. However, the Fleet survey found that 43 percent of the non-sleeved engines in the survey (the vast majority of which would be classified as MHDDEs) are never rebuilt.[17] Most of the new LHDDEs are also non-sleeved and are less expensive than MHDDEs, being designed to compete with HDGEs. Since they are less costly to replace, and in some cases are not designed to be rebuilt, it is likely that even fewer LHDDEs than MHDDEs would be rebuilt. EPA will therefore continue the linkage between LHDDEs and HDGEs, and establish the assigned useful-life period for LHDDEs at 110,000 miles.

Turning now to MHDDEs, EMA felt that the figure of 203,000 miles quoted in the SDR survey for Class VI vehicles was too large for the MHDDE subclass, because the Class VI vehicles probably used some engines which would be considered as premium HHDDEs. EPA concurs with EMA's assessment. Second, although data in the Fleet article indicated that buses are typically powered by MHDDEs, this application may not be representative of MHDDE usage. Therefore, EPA accepts EMA's suggestion that MHDDE useful life should be based in part on the average non-sleeved engine mileage to overhaul reported in the Fleet survey (175,000). The ATA survey rebuild mileage of 176,000 for diesel straight trucks also lends support to this figure. An average of the sources suggested by EMA (including the SDR, ATA, and Fleet, rebuild surveys and engineering estimates by Little and Myers) yields an average rebuild mileage of 173,300 miles.

However, while EPA accepts the average of these data as valid for the MHDDEs that are rebuilt, the Fleet survey also indicates that an average of 43 percent of the non-sleeved engines do not get rebuilt. This is a significant percentage and must also be factored in to the determination of the useful-

* The straight truck data in the ATA survey included both gasoline and diesel trucks. The median was 150,000 miles and the mean was 170,470 miles. The relative values of the median and the mode depict a disjointed data set. Based on the HDGE analysis above, it was concluded that the median value was relatively low due to the HDGEs. So the modal value probably represented the diesel straight trucks. Therefore, the 200,000-mile value was used.

life period for MHDDEs. EPA expects that non-rebuilt engines would be operated somewhat past the point where the average rebuild would normally occur, as owners attempted to extract the maximum service. The ATA survey provides a modal value of 200,000 miles for trade-in of straight trucks.[18]* Since few owners are likely to go to the expense of a rebuild at 173,000 miles, and then trade in the truck 27,000 miles later, 200,000 miles is a reasonable estimate of useful life for non-rebuilt engines.

Therefore, addition of 57 percent of 173,300 miles (98,781) to 43 percent of 200,000 miles (86,000) yields a weighted average of 184,781 miles, so EPA will establish a period of 185,000 miles as the MHHDE assigned useful life.

Given the change in the HDDE classification approach from gross vehicle weight to what is essentially an application-based approach, there also is a need for a reassessment of the assigned useful-life period for HHDDEs, just as was done for MHDDEs. The heavy heavy-duty diesel engine subclass originally proposed by EPA covered GVW Classes VII and VIII trucks and buses, and these vehicles included some engines that would now be classified as MHDDEs or even LHDDEs under the EMA approach. Caterpillar's comments indicated, for example, that its 3208 engine, which the manufacturer considered an MHDDE, was sold "almost solely" in Class VII or VIII GVW vehicles.[19] International Harvester Corporation, which also manufactures LHDDE and MHDDEs, stated that "every diesel engine" the company offers for sale could be found in Class VII or VIII GVW vehicles.[20] The assigned useful-life period for heavy heavy-duty diesel engines in the proposal reflected this vehicle mix and is therefore understated for HHDDEs under the EMA approach. With the adoption of EMA's subclasses based on application rather than GVW, the HHDDE subclass will now be predominantly premium-engines designed for long-haul, high-mileage service applications, necessitating an adjustment in the assigned useful-life period. The SDR Classes VII and VIII data are not adequately representative of premium HHDDEs to serve as the basis for the analysis since these vehicles would use some MHDDEs, just as EMA asserted that the Class VI SDR figure was overstated because it included some HHDDEs. However the SDR survey determined a rebuild mileage of 303,000 for "long haul" usage engines, which would clearly reflect HHDDEs. Also, the Fleet average rebuild mileage for sleeved engines (281,000 miles) and the ATA mean rebuild mileage for "tractors" (296,862 miles) are clearly representative of the type of engine and operation in question. An average of these three sources plus the A.D. Little engineering estimate (290,000 miles) yields a mileage of 292,716 miles. Based on this average, EPA will assign a useful-life value of 290,000 miles for this subclass.

If the median or modal values in the ATA survey (300,000 miles) were substituted for the mean, the resulting average of the four sources would be 293,500 miles. Using the EMA approach to the HDDE subclasses effectively addresses the comment concerning the grouping together of Class VII and Class VIII trucks in the heavy heavy-duty diesel subclass proposed by EPA.

The final area to be considered is the number of years, as opposed to miles, in the assigned useful-life values. EMA stated that EPA's position appeared to be that a truly representative years-to-rebuild value was not necessary "if an accurate mileage value is prescribed."[21] EMA did not agree with this position, saying that an accurate figure for equivalent years to rebuild was necessary due to the fact that many HDDEs accumulate a great many hours of running time without accumulating many miles. Actually, EPA has never maintained the position claimed by EMA. In most cases, the period of years was roughly equivalent to miles of use as described above. The Michigan Technological University (MTU) vehicle mileage tables used in the EPA Emission Factors Program, the National Highway Traffic Safety Administration (NHTSA) mileage tables, and the Department of Energy "Highway Fuel Consumption Model" (DOE) annual vehicle mileage tables were consulted in determining years to the end of useful life for all categories except Classes VII and VIII.[22] In the latter case EPA found that while most applications were very high mileage (i.e., the useful-life mileage would be accumulated in 3-5 years), enough relatively low-mileage applications would be included so that a considerably longer period of years was necessary to be representative of their full useful lives. Examples of these low-mileage applications include concrete mixers, fire trucks, and garbage packers. Although some of these applications will now likely be included in the MHDD service class, EPA believes that some HHDDEs will continue to be sold for this kind of use. An extended period of years should not affect long-haul intercity vehicles for which the useful-life mileage total will become the limiting factor, but will allow a more representative useful-life period for the lower mileage applications. Therefore, EPA will adjust the useful-life year values for approximate equivalency with the revised useful-life mileages, except for HHDDEs, which will be assigned the same useful-life years as MHDDEs (i.e., 8 years).

Conclusions

Based on the above analysis, and the HDDE classification system suggested by EMA, EPA finds it appropriate to revise the useful-life values as follows:

	Mileage		Years	
	Proposed	Final	Proposed	Final
LDT	130,000 mi.	120,000 mi.	12 years	11 years
HDGE/LHDDE	120,000 mi.	110,000 mi.	10 years	8 years
MHDDE	200,000 mi.	185,000 mi.	10 years	8 years
HHDDE	275,000 mi.	290,000 mi.	10 years	8 years

EPA concludes that scrappage data should not be excluded from the assigned useful-life calculations, as EMA suggested, but has no objection to inclusion of other data as desired by EMA. The assigned useful-life period will be the same for all LDTs, rather than setting a shorter period for the lighter 4-cylinder vehicles as desired by VW and others. Finally, it should be repeated that a manufacturer has the option to request an alternative useful-life period for an individual engine family if there is reason to believe that the assigned useful-life value is unrepresentative.

Minor Issues

Summary of Comments

Manufacturers have raised a number of minor issues under the modified full-life provisions. GM asked whether a manufacturer would be expected to test engines after they were worn out to determine a deterioration factor (DF) for the full assigned useful life and also how a manufacturer would determine the DF if the test engine failed before reaching the assigned useful-life value. Mack Trucks suggested that bench testing would be sufficient for checking the durability of HDDE emission control components and that there would be no need for full-life useful life. Ford presented its opinion that the manufacturer's certification statement, to the effect that a properly maintained engine will conform to the applicable standards for its full useful life, must be qualified to take into consideration engine wearout before the end of the assigned useful-life period. The ATA wanted EPA to publish useful-life values for all HDEs. Lastly, AMC stated that full life would break the link allowing shared technology between light-duty vehicles (LDVs) and LDTs, since LDTs would now require more durable components. AMC predicted increased costs to both manufacturers and consumers as a result of breaking this LDV/LDT link.

Analysis of Comments

In response to GM's concerns, there will be no specific durability testing requirement under modified full life. As long as the manufacturers are satisfied that emissions will not exceed the standard for the useful life of their vehicles/engines, they are free to determine deterioration factors using any method desired, as long as good engineering practices are followed. The bench testing option advanced by Mack Trucks might be a more cost-effective way to assess component durability, for example, if the manufacturer felt confident of the accuracy of that approach. However, EPA disagrees that such bench testing is adequate to eliminate the need for the full-life useful-life requirement. EPA believes that the full-life requirement is still necessary to provide increased assurance of durable component design by holding the manufacturer accountable for lifetime emissions compliance. Bench testing represents one potential approach to durability assessment which the manufacturers may choose.

With regard to Ford's point concerning the certification statement, elimination of the useful-life labeling requirement also removes the current compliance statement required for LDTs and HDEs under 40 CFR 86.084-35. However, for vehicle/engine classes where a single assigned useful-life value is specified, that label is replaced by a general compliance label, as is currently specified for LDTs and HDEs. This label states that the vehicle/engine conforms to the applicable model year EPA regulations. Since HDDEs are not all assigned the same useful-life period, they will also be labeled to indicate the subclass for which they are certified. Any LDT/HDE for which an alternative useful-life value is approved by the Administrator will also be labeled with the alternative useful-life value. To address the Ford concern, EPA will retain the current qualifying statement that "This engine's actual life may vary, depending on its service applications."

Since engine-specific useful-life values are replaced by assigned useful-life periods, there should be no need to publish individual useful-life data as requested by the ATA. The assigned useful-life values for classes/subclasses are published in this rulemaking. In addition, as outlined above, HDDE manufacturers will be required to label their engines with the service classes for which they are certified. As requested by ATA, any vehicle/engine for which an alternative useful-life value was approved would also be labeled with the alternative value. Since ATA's interests seem to be primarily in the area of HDDEs which will all be labeled with the subclass as a matter of course, and since alternative useful-life values will be indicated if applicable, EPA feels ATA's needs will be addressed by the above measures.

Finally, EPA does not believe the impact of full-life useful life will be so great as to inhibit the sharing of technology between LDVs and LDTs, as AMC suggests. It is hardly cost-effective to redesign a component or design a replacement for it and then continue to produce the old one in parallel with production of the new or redesigned component.

The Agency finds it difficult to believe that any manufacturer would choose this course of action, particularly since it provides a much narrower base for amortization of development and tooling costs than would application of the component to the entire product line. Since the applications and technology are basically similar for both LDVs and LDTs, EPA believes that commonality of components will continue to be standard practice. If the durability of some of these components improves as a result of the full-life requirement for LDTs, it will result in an additional benefit to the LDV buyer and improve the emissions of the LDV. There is no reason, however, why separate components need be produced for LDVs and LDTs.

Conclusions

Most of the minor certification issues require no action on EPA's part. The qualifying statement on the label that average useful life will vary according to service application will address Ford's concerns. ATA's request for publication of the assigned useful-life values is addressed by the values published in the rulemaking and by the labeling requirement for HDDE subclasses and for alternative useful-life periods. AMC's fear that full-life useful life will break the traditional technology link between LDVs and LDTs appear overstated and EPA rejects the idea that any duplication of effort or waste of resources will result.

References

1. Summary and Analysis of Comment to the NPRM, 1983 and Later HDEs, pp. 105-110, December 1975.

2. Summary and Analysis of Comment to the NPRM, 1983 and Later LDTs, p. 1-3, May 1980.

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14. "Determination of Useful-Life Values for Light-Duty Trucks and Heavy-Duty Engines," EPA Memorandum from Robert J. Johnson, December 13, 1982.

15. Response to January 12, 1983 NPRM, Public Docket A-81-II, IV-D-86, p. 16, April 18, 1983.

16. Letter from Thomas C. Young to Kathleen M. Bennett, Office of Air, Noise and Radiation, May 3, 1982.

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17. *Fleet Maintenance and Specifying*, Vol. 7, No. 7, May 1981.

18. See Reference 9, p. 6.

19. Caterpillar Response to January 12, 1983 NPRM, Public Docket A-81-11, IV-D-77, p. 4, April 13, 1983.

20. International Harvester Response to January 12, 1983 NPRM, Public Docket A-81-11, IV-D-81, p. 23, April 18, 1983.

21. EMA Response to January 12, 1983 NPRM, Public Docket A-81-11, IV-D-83, p. 53.

22. "Conversion of Useful-Life Mileages to Periods of Years," EPA Memorandum, Robert J. Johnson, July 25, 1983.

3. Issue: Alternative Test Cycles

A. The Real Time Cycle for Heavy-Duty Diesel Engines

Summary of the Issue

An alternative heavy-duty diesel test cycle, the Real Time Cycle (RTC), has been developed by the Caterpillar Tractor Company (Caterpillar). It was developed in response to industry-wide concern over the methodology used to generate the EPA cycle and its resulting representativeness.

Summary of Comments

Most manufacturers and the Engine Manufacturers Association (EMA) have made specific recommendations concerning the use of the RTC for certification testing. Some of the recommendations, however, have changed over time as additional data were gathered on the RTC. A brief review of the chronology of events is appropriate for this discussion.

The EMA and member companies recommended in April 1982 that EPA adopt as a test option the use of the RTC. This recommendation was based upon the industry's concern about the representativeness of the EPA cycle.

Shortly thereafter, EPA reviewed the technical basis for the creation of the RTC. (Part of EPA's earlier analysis is reproduced below.) EPA also reviewed the available data base wherein emission results from both cycles were compared. At the time, about 30 comparative data points were available. EPA's draft analysis noted that a net difference in emissions existed between the test cycles, and recommended that the applicable emission standards be adjusted to account for the offset. This was recommended so as to preclude an effective relaxation of the emission requirements promulgated on January 21, 1980. EPA's original analysis (see Appendix, Chapter 5 of the Transient Test Study) was distributed for public comment in early summer 1982.

The EMA and member companies reviewed EPA's draft analysis, and over time, in both informal and formal communications, took issue with two of EPA's conclusions. First, EMA disputed the need for an emission standard adjustment. The argument was made that the heavy-duty diesel cycle was never used in the standards development process, and the use of a specific diesel cycle is decoupled from the level of the standards. (The heavy-duty gasoline engine cycle was used to derive the statutory emission standards.) Secondly, if an adjustment were to be made, EMA disagreed with the methodology EPA used to derive the equivalently stringent standard. EMA proposed a methodology which yielded an RTC-based hydrocarbon (HC) emission standard of 1.20 grams per brake horsepower-hour (g/BHP-hr), using the latest available data. EMA and its member companies formalized their position in a May 13, 1983 submission to EPA. They also recommended, contrary to earlier recommendations, that only a single test cycle be used for certification. If the RTC cycle was not made available with a HC standard of 1.2 g/BHP-hr, the industry preferred the use of the EPA cycle at the 1.3 g/BHP-hr HC standard.

Analysis of Comments

In this analysis, we address the construction, representativeness, and relative stringency of the RTC. Methodologies for emission standard adjustments are also evaluated, as is the justification for such an adjustment. Finally, the selection of a certification test cycle is made.

Cycle Development[3]

Caterpillar developed the RTC because of concern over the accuracy of simulation of in-use truck operation represented by the EPA cycles. This concern stemmed from alleged instrumentation problems in the CAPE-21 project which they argued resulted in a significant amount of questionable data being accepted into the data base, and from the methodology EPA used to generate the cycle. Caterpillar's objectives in developing the RTC were to generate a cycle from the portion of the CAPE-21 data base which it considered valid, and to construct the cycle so it better represented its judgment of real-world truck operation.

The entire data base was first edited to remove what Caterpillar believed to be questionable data. This editing left 23 truck-days of data, or about 25 percent of the original data base. Statistical parameters were then chosen to characterize the edited data base. These were mean values and cumulative distributions of percentage rpm, percentage power, and positive percentage rpm. The percentage idle time and distribution in length of idle were also used. These statistical parameters then became the target values for the construction of the new test cycle.

To construct the new test cycle, the data were broken down into the smallest elements which did not interrupt the normal driving sequence. These elements were defined as the vehicle operational events which occurred between vehicle stops. The elements were then assembled into trial test segments which matched, as closely as possible, the desired statistics of the categories they represented. The categories were: New York

Freeway (NYF), New York Non-Freeway (NYNF), Los Angeles Freeway (LAF), and Los Angeles Non-Freeway (LANF). The idle time and category weighting were adjusted to match the original CAPE-21 data base, since it was judged unlikely that instrument error would change these parameters. The trial test segments were then tested against the data base for maximum deviation of cumulative distributions and then were compared visually. The best cycles were selected and assembled into an entire driving cycle.

The result was a heavy-duty diesel engine (HDDE) driving cycle, the "Real Time Cycle," which matched very closely the statistics of the edited CAPE-21 data base, and which the diesel engine manufacturers believed was more representative of in-use truck operation than the EPA cycle.

Statistical Analysis

A comparison of the target statistics from the edited data base, the RTC statistics, and the EPA cycle statistics is shown in Table 3-1. Additional statistics from the RTC, EPA cycle, and the original CAPE-21 data base are listed in Table 3-2. The most important statistical differences between the RTC and the EPA cycle are:

1. The RTC includes a NYF segment, while the EPA cycle does not.* (The NYF segment is higher in mean percentage rpm and higher in mean percentage power than the NYNF segment.)

2. The RTC is 5.2 percent higher in mean percentage power, overall, than the EPA cycle.

3. The RTC is 4.8 percent lower in percentage idle time, overall, than the EPA cycle.

4. The sequential ordering of the cycle segments on the RTC is LANF, LAF, NYF, and NYNF. The ordering on the EPA cycle is NYNF, LANF, LAF, NYNF.

The statistical differences cited here may or may not affect engine emission levels. A potentially significant factor is that the observed engine work done over the test cycle (BHP-hr) is higher by 16-18 percent on the RTC. Furthermore, the reordering of the segments in the RTC permits the engine to operate in the high power LAF mode earlier in the cycle, which may lead to an earlier engine warm-up (although

* EPA omitted the NYF segment because invalid data had been included in the data base and the weighting for this segment was small compared to the other segments.[4]

Table 3-1

Target, RTC, and EPA Cycle Statistics [3]

	Los Angeles Non-Freeway			Los Angeles Freeway		
	Target	Real Time	EPA	Target	Real Time	EPA
Average rpm (%)	40.7	41.8	43	80.0	83.5	83
Average Power (%)	24.1	25.9	26	58.9	56.4	56
Average Positive Acceleration	4.6	5.7	6.1	1.9	1.2	2.4
Idle Time (%)	35.0	32.7	34	2.0	1.4	2.3
Category Weighting	23.7	27.3	25.0	26.3	25.1	25.0

	Los Angeles Non-Freeway			Los Angeles Freeway		
	Target	Real Time	EPA	Target	Real Time	EPA
Average rpm (%)	41.5	47.1	--	17.7	19.8	20
Average Power (%)	41.0	54.4	--	19.4	22.3	16
Average Positive Acceleration	2.8	4.6	--	3.8	3.6	5.6
Idle Time (%)	19	21	--	51.0	51.0	55
Category Weighting	9.0	5.9	0	41.0	41.7	50.0

	Overall		
	Target	Real Time	EPA
Average rpm (%)	41.7	43.4	41.5
Average Power (%)	32.8	33.7	28.5
Average Positive Acceleration	3.9	4.2	4.6
Idle Time (%)	31.4	31.8	36.6

Table 3-2

RTC, EPA Cycle, CAPE-21 Data Base Statistics

Parameter	RTC	EPA	CAPE-21
Torque			
Mean (%)	30.57	28.32	27.00
Percent of Cycle Time			
Acceleration (%)	18.21	15.68	15.10
Deceleration (%)	18.37	16.85	15.25
Cruise (%)	22.48	20.43	18.75
Motor (%)	7.98	11.43	15.00
Idle (%)	32.96	35.61	35.00
RPM			
Mean (%)	42.78	41.52	41.75
Percent of Cycle Time			
Acceleration (%)	23.45	21.77	21.50
Deceleration (%)	22.48	21.93	19.50
Cruise (%)	19.74	16.10	19.50
Idle (%)	34.33	40.20	39.00

operation in the LAF segment of the RTC is initially cooler than on the EPA cycle). Inclusion of the NYF segment in lieu of another NYNF segment is one obvious reason why the RTC BHP-hr is higher than that of the EPA cycle.

Test Cycle Correlation

Heavy-duty diesel engine manufacturers and EPA have now tested many engines on both the RTC and the EPA cycle for the purpose of comparing emissions results. All of the available data have been collected and are summarized in Table 3-3. Results are also plotted in Figures 3-1, 3-2, and 3-3. Since typical diesel carbon monoxide (CO) emissions are much lower than statutory levels, this pollutant comparison was not included. Immediately obvious is the fact that emission levels are different between the candidate test cycles.

The HC emissions difference between the test cycles is explainable and expected. A decrease in brake specific HC emission rates at higher engine loads is typically observed on diesel engines. Consider the following mechanism for such an observation: in diesel engines, HC emissions are in large part attributable to residual fuel in the injector sac. The sac volume is constant regardless of the amount of fuel injected; as the load is increased (i.e., more fuel is injected), the mass rate of HC emissions from the sac remains constant. However, the brake specific rate of HC emissions (g/BHP-hr) decreases at higher loads since the denominator (power-hour) increases while the numerator (mass HC) remains the same. This could explain most of the difference in HC emissions, given that the RTC is a higher power test cycle and that both cycles exercise the engine in fundamentally the same way.

The constant residual sac volume is likely not the only mechanism by which emissions from each cycle are different. However, further discussion of exact mechanisms at this point is not important. What is important is the fact that the RTC cycle correlates very well with the EPA cycle (and vice versa) for many different engines. This indicates that emissions from one cycle can be accurately predicted from those of the other. The excellent correlation also indicates that both cycles should be comparable in the ability to predict in-use emission reductions, and that there is no inherent advantage in using one cycle over the other. Given the difference in cycle generation methodologies and the correlatable emission results, and the reasonable presumption that the HC emissions offset is primarily attributable to the difference in load factor between the cycles, EPA concludes that both cycles are comparably representative. Each by itself would be technically acceptable for certification testing.

Table 3-3

Summary of Emissions Data EPA Cycle vs. Real Time Cycle

Engine/ Test Number[a]	Test Lab	Cycle	Number and Type of Tests (CS)	Number and Type of Tests (HS)	Combined Cold/Hot Start: Regressions	Combined Cold/Hot Start: HC (g/BHP-hr)	Combined Cold/Hot Start: NOx (g/BHP-hr)	Combined Cold/Hot Start: Part. (g/BHP-hr)	Hot Start Only: Regressions[b]	Hot Start Only: HC (g/BHP-hr)	Hot Start Only: NOx (g/BHP-hr)	Hot Start Only: Part. (g/BHP-hr)
Mack ETSX-676[c]	EPA	EPA		4		--	--	--	1,8,10	.65	8.40	.752
		RTC		4		--	--	--		.55	8.56	.777
Cummins VTB-903[c]	EPA	EPA		4		--	--	--	1,8,10	1.60	5.07	.544
		RTC		4		--	--	--		1.27	5.01	.504
IHC DT-210	IHC[e]	EPA	1-3	2-7	1,2,3,4,	.89	7.20	--		--	--	--
		RTC	1-3	2-7	8,9,10,11	.78	6.80	--		--	--	--
IHC DTI-210	IHC	EPA	1-3	2-7	1,2,3,4,	1.07	4.15	--		--	--	--
		RTC	1-3	2-7	8,9,10,11	.95[i]	4.16	--		--	--	--
IHC DTI-180	IHC	EPA	1-3	2-7	1,2,3,	1.18	4.94	--	5,6,7	1.14	--	--
		RTC	1-3	2-7	4,5,6,7, 8,9,10,11	1.06	4.73	--		1.05	--	--
IHC 9.0L	IHC	EPA	1-3	2-7	1,2,3,4,5,	2.03	7.18	--	5,6,7	2.04	--	--
		RTC	1-3	2-7	6,7,8,9, 10,11	1.90	7.52	--		1.90	--	--
Cummins #1[f]	Cummins	EPA		2		--	--	--	1,8,9,10	.55	7.50	.46
		RTC		2		--	--	--		.48	7.46	.43
Cummins #2	Cummins	EPA		2		--	--	--	1,8,9,10	1.19	8.10	.66
		RTC		2		--	--	--		.91	7.92	.66
Cummins #3	Cummins	EPA		2		--	--	--	1,8,9,10	.87	7.37	.70
		RTC		2		--	--	--		.63	7.29	.56
Cummins #4	Cummins	EPA		2		--	--	--	1,8,9,10	.94	4.63	.94
		RTC		2		--	--	--		.67	5.42	.94
Cat 3208	IHC	EPA	5	12		--	--	--	1	1.30	7.68	.70
		RTC	4	6		--	--	--		.84	8.57	.60

Table 3-3 (cont'd)

Summary of Emissions Data EPA Cycle vs. Real Time Cycle

Engine/ Test Number[a]	Test Lab	Cycle	Number and Type of Tests (CS)	Number and Type of Tests (HS)	Combined Cold/Hot Start: Regressions	Combined Cold/Hot Start: HC (g/BHP-hr)	Combined Cold/Hot Start: NOx (g/BHP-hr)	Combined Cold/Hot Start: Part. (g/BHP-hr)	Hot Start Only: Regressions[b]	Hot Start Only: HC (g/BHP-hr)	Hot Start Only: NOx (g/BHP-hr)	Hot Start Only: Part. (g/BHP-hr)
Mack #1[g]	Mack	EPA			1,2[d],8,	.46	5.6	.51		--	--	--
		RTC			9,10,11	.41	5.9	.46		--	--	--
Mack #2	Mack	EPA			1,2[d],8,	.55	7.8	.79		--	--	--
		RTC			9,10,11	.46	8.4	.69		--	--	--
Mack #3	Mack	EPA			1,2[d],8,	1.10	10.3	.85		--	--	--
		RTC			9,10	.87	9.0	.69		--	--	--
Cat 3208[c]	IHC	EPA	5	11	1,2,5,	1.30	7.59	.70	5	1.24	--	--
		RTC	4	6	8,10,11	.85	8.59	.60		.81	--	--
Mack ETSX-676[c]	Cat	EPA	2	12	1,2,3,	.73	6.82	.53	5,6	.74	--	--
		RTC	1	7	4,5,6,8,10	.65	7.62	.63		.64	--	--
IHC DTI-466B[c]	Cat	EPA	2	15	1,2,3,	1.00	4.44	.69	5	.95	--	--
		RTC	1	6	4,5,8,10	.90	4.30	.70		.90	--	--
Cat 3208	Cat	EPA	5	11	1[h],2,3,	.97	8.40	.86	5,6,7	.92	--	--
		RTC	1	7	4[h],5,6,7, 8,9,10,11	.88	8.79	.88		.85	--	--
Cat 3406	Cat	EPA	3	14	1,2,3,	.49	4.82	.83	5,6,7	.48	--	--
		RTC	1	6	4,5,6,7, 8,9,10,11	.40	5.00	.73		.39	--	--
Cat 3208	Cat	EPA	2	6	1,2,3,	1.07	9.11	.854	5,6,7	1.07	--	--
		RTC	3	8	4,5,6,7,8, 9,10,11	.98	9.24	.712		.97	--	--
Cat 3208 Model 1	Cat	EPA	2	3	1,2,3,4,5,	1.04	14.13	1.04	5,6,7	1.02	--	--
		RTC	5	5	6,7,8,9,10,11	.88	13.96	.820		.88	--	--

Table 3-3 (cont'd)

Summary of Emissions Data EPA Cycle vs. Real Time Cycle

Engine/ Test Number[a]	Test Lab	Cycle	Number and Type of Tests (CS)	(HS)	Combined Cold/Hot Start: Regressions	HC (g/BHP-hr)	NOx (g/BHP-hr)	Part. (g/BHP-hr)	Hot Start Only: Regressions[b]	HC (g/BHP-hr)	NOx (g/BHP-hr)	Part. (g/BHP-hr)
Cat 3208	Cat	EPA	2	8	1,2,3,4,5,	2.70	6.38	1.24	5,6,7	2.73	--	--
Model 2		RTC	3	6	6,7,8,9,10, 11	2.40	6.42	.974		2.38	--	--
Cat 3406	Cat	EPA	3	4	1,2,3,4,	.48	7.62	.782	5,6,7	.45	--	--
		RTC	3	4	5,6,7,8,9, 10,11	.37	7.26	.653		.35	--	--
IHC DT-466	IHC	EPA			2,5,6,7,	1.02	--	--	5,6,7	.98	--	--
(210)		RTC			8,9,10,11	.95	--	--		.94	--	--
Cat 3406,	Cat	EPA	2	5	1,2,3,4,	.60	11.82	.726	5,6,7	.52	--	--
Model 1		RTC	3		5,6,7,8,9 10,11	.47	11.56	.601		.43	--	--
Cat 3406,	Cat	EPA	2	5	1,2,3,4,	.57	4.03	1.79	5,6,7	.53	--	--
Model 2		RTC	2	4	5,6,7, 8,9,10,11	.50	3.78	1.33		.49	--	--
Cat 3406,	Cat	EPA	3	4	1,2,3,4,	.89	4.12	2.20	5,6,7	.82	--	--
Model 3		RTC	2	6	5,6,7,8, 9,10,11	.77	3.64	2.27		.74	--	--
Cummins	DDA	EPA		1		--	--	--	1,8,10	1.98	5.07	--
VTB-903[c]		RTC		1		--	--	--		1.73	4.80	--
DDA 8V-92,	DDA	EPA		2		--	--	--	1,8,9,10	.81	4.60	--
Model 1		RTC		2		--	--	--		.72	4.26	--

Table 3-3 (cont'd)

Summary of Emissions Data EPA Cycle vs. Real Time Cycle

Engine/ Test Number[a]	Test Lab	Cycle	Number and Type of Tests (CS)	Number and Type of Tests (HS)	Combined Cold/Hot Start: Regressions	Combined Cold/Hot Start: HC (g/BHP-hr)	Combined Cold/Hot Start: NOx (g/BHP-hr)	Combined Cold/Hot Start: Part. (g/BHP-hr)	Hot Start Only: Regressions[b]	Hot Start Only: HC (g/BHP-hr)	Hot Start Only: NOx (g/BHP-hr)	Hot Start Only: Part. (g/BHP-hr)
DDA 8V-92,	DDA	EPA		3		--	--	--	1,8,9,10	.68	8.38	--
Model 2		RTC		3		--	--	--		.73	7.69	--
DDA 8V-71TA[c]	Cat	EPA			2,3,4,5,6,	.63	--	--	5,6	.63	--	--
		RTC			8,10	.61	--	--		.62	--	--
IHC 466B[c]	Cummins	EPA				--	--	--	8,10	.66	4.01	.76
		RTC				--	--	--		.62	4.09	.77
DDA 8.2L	DDA	EPA		3		--	--	--	1,8,9,10	1.14	5.78	--
		RTC		3		--	--	--		.92	5.44	--
Cummins	Cummins	EPA			2,8,9,10,11	1.66	4.97	.91		--	--	--
VTB-903		RTC				1.37	5.14	.76		--	--	--
IHC DT-466[c]	EPA	EPA				--	--	--	8,10	.64	3.53	.65
		RTC				--	--	--		.62	3.53	.66
DDA 8V-71TA	DDA	EPA			2,8,9,10,11	.55	6.75	.35		--	--	--
		RTC				.59	6.96	.33		--	--	--
Mack ETSX-676	Mack	EPA				--	--	--	8,9,10	.78	7.86	.56
		RTC				--	--	--		.71	7.4	.53
IHC DT-466	IHC	EPA			2,5,6,7,	.75	--	--	5,6,7	.68	--	--
		RTC			8,9,10,11	.63	--	--		.62	--	--
3241	Cummins	EPA		1		--	--	--	8,9,10	.88	5.45	--
3242		RTC		1		--	--	--		.69	5.57	--
3261	Cummins	EPA		1		--	--	--	8,9,10	1.3	5.90	--
3263		RTC		1		--	--	--		2.51[j]	5.80	--

Table 3-3 (cont'd)

Summary of Emissions Data EPA Cycle vs. Real Time Cycle

Engine/ Test Number[a]	Test Lab	Cycle	Number and Type of Tests (CS)	Number and Type of Tests (HS)	Combined Cold/Hot Start: Regressions	Combined Cold/Hot Start: HC (g/BHP-hr)	Combined Cold/Hot Start: NOx (g/BHP-hr)	Combined Cold/Hot Start: Part. (g/BHP-hr)	Hot Start Only: Regressions[b]	Hot Start Only: HC (g/BHP-hr)	Hot Start Only: NOx (g/BHP-hr)	Hot Start Only: Part. (g/BHP-hr)
3301	Cummins	EPA		1		--	--	--	8,9,10	.89	5.80	--
3302		RTC		1		--	--	--		.68	5.84	--
3321	Cummins	EPA		1		--	--	--	8,9,10	.84	6.56	--
3322		RTC		1		--	--	--		.64	6.53	--
3341	Cummins	EPA		1		--	--	--	8,9,10	.91	6.53	--
3342		RTC		1		--	--	--		.73	6.42	--
3391	Cummins	EPA		1		--	--	--	8,9,10	1.08	6.96	--
3393		RTC		1		--	--	--		.60	6.63	--
3413	Cummins	EPA		1		--	--	--	8,9,10	.84	7.16	--
3414		RTC		1		--	--	--		.64	6.98	--
3461	Cummins	EPA		1		--	--	--	8,9,10	.82	6.68	--
3463		RTC		1		--	--	--		.58	6.77	--
3501	Cummins	EPA		1		--	--	--	8,9,10	.80	5.37	--
3502		RTC		1		--	--	--		.65	5.66	--
3531	Cummins	EPA		1		--	--	--	8,9,10	.83	4.42	--
3532		RTC		1		--	--	--		.72	4.53	--
3612	Cummins	EPA		1		--	--	--	8,9,10	.77	7.40	--
3613		RTC		1		--	--	--		.61	7.38	--
3641	Cummins	EPA		1		--	--	--	8,9,10	.72	7.32	--
3642		RTC		1		--	--	--		.57	7.28	--

Table 3-3 (cont'd)

Summary of Emissions Data EPA Cycle vs. Real Time Cycle

Engine/ Test Number [a]	Test Lab	Cycle	Number and Type of Tests (CS)	(HS)	Combined Cold/Hot Start Regressions	HC (g/BHP-hr)	NOx (g/BHP-hr)	Part. (g/BHP-hr)	Hot Start Only Regressions [b]	HC (g/BHP-hr)	NOx (g/BHP-hr)	Part. (g/BHP-hr)
3761	Cummins	EPA		1		--	--	--	8,9,10	2.07	6.13	--
3762		RTC		1		--	--	--		1.58	6.27	--
3742	Cummins	EPA		1		--	--	--	8,9,10	.93	6.77	--
3743		RTC		1		--	--	--		.72	7.01	--
3761	Cummins	EPA		1		--	--	--	8,9,10	.89	6.24	--
3762		RTC		1		--	--	--		.65	6.11	--
3781	Cummins	EPA		1		--	--	--	8,9,10	1.58	6.72	--
3782		RTC		1		--	--	--		.98	6.80	--
3791	Cummins	EPA		1		--	--	--	8,9,10	.26	6.05	--
3792		RTC		1		--	--	--		.17	6.10	--
3841	Cummins	EPA		1		--	--	--	8,9,10	.88	7.86	--
3842		RTC		1		--	--	--		.54	8.11	--
3852	Cummins	EPA		1		--	--	--	8,9,10	.85	7.19	--
3853		RTC		1		--	--	--		.67	7.52	--
3861	Cummins	EPA		1		--	--	--	8,9,10	.60	7.22	--
3862		RTC		1		--	--	--		.47	7.54	--
3871	Cummins	EPA		1		--	--	--	8,9,10	.56	7.49	--
3872		RTC		1		--	--	--		.43	7.54	--
3881	Cummins	EPA		1		--	--	--	8,9,10	.65	7.35	--
3882		RTC		1		--	--	--		.53	7.27	--
3961	Cummins	EPA		1		--	--	--	8,9,10	.74	6.55	--
3962		RTC		1		--	--	--		.59	6.58	--

Table 3-3 (cont'd)

Summary of Emissions Data EPA Cycle vs. Real Time Cycle

Engine/ Test Number [a]	Test Lab	Cycle	Number and Type of Tests (CS)	Number and Type of Tests (HS)	Combined Cold/Hot Start Regressions	Combined Cold/Hot Start HC (g/BHP-hr)	Combined Cold/Hot Start NOx (g/BHP-hr)	Combined Cold/Hot Start Part. (g/BHP-hr)	Hot Start Only Regressions [b]	Hot Start Only HC (g/BHP-hr)	Hot Start Only NOx (g/BHP-hr)	Hot Start Only Part. (g/BHP-hr)
4011	Cummins	EPA		1		--	--	--	8,9,10	.69	6.36	--
4012		RTC		1		--	--	--		.50	6.38	--
4031	Cummins	EPA		1		--	--	--	8,9,10	.65	7.67	--
4032		RTC		1		--	--	--		.53	7.92	--
4042	Cummins	EPA		1		--	--	--	8,9,10	1.48	6.82	--
4043		RTC		1		--	--	--		1.18	6.91	--
4051	Cummins	EPA		1		--	--	--	8,9,10	.67	7.43	--
4052		RTC		-1		--	--	--		.53	7.55	--
4081	Cummins	EPA		1		--	--	--	8,9,10	.86	6.33	--
4082		RTC		1		--	--	--		.72	6.44	--
4245	Cummins	EPA		1		--	--	--	8,9,10	.83	3.83	--
4246		RTC		1		--	--	--		.66	4.74	--
4261	Cummins	EPA		1		--	--	--	8,9,10	.75	6.57	--
4262		RTC		1		--	--	--		.63	6.90	--
4331	Cummins	EPA		1		--	--	--	8,9,10	.77	6.05	--
4332		RTC		1		--	--	--		.68	6.26	--
4351	Cummins	EPA		1		--	--	--	8,9,10	.88	5.91	--
4352		RTC		1		--	--	--		.74	5.62	--
4381	Cummins	EPA		1		--	--	--	8,9,10	1.02	6.43	--
4382		RTC		1		--	--	--		.77	6.59	--
4401	Cummins	EPA		1		--	--	--	8,9,10	.76	6.39	--
4102		RTC		1		--	--	--		.53	6.29	--

Table 3-3 (cont'd)

Summary of Emissions Data EPA Cycle vs. Real Time Cycle

Engine/ Test Number [a]	Test Lab	Cycle	Number and Type of Tests (CS)	(HS)	Combined Cold/Hot Start Regressions	HC (g/BHP-hr)	NOx (g/BHP-hr)	Part. (g/BHP-hr)	Hot Start Only Regressions [b]	HC (g/BHP-hr)	NOx (g/BHP-hr)	Part. (g/BHP-hr)
4451	Cummins	EPA		1		--	--	--	8,9,10	.61	6.30	--
4452		RTC		1		--	--			.58	6.23	--
4521	Cummins	EPA		1		--	--		8,9,10	.75	6.47	--
4522		RTC		1		--	--			.56	6.48	--
4561	Cummins	EPA		1		--	--	--	8,9,10	.72	4.09	--
4562		RTC		1		--	--	--		.63	4.14	--
4581	Cummins	EPA		1		--	--	--	8,9,10	.66	4.36	--
4582		RTC		1		--	--	--		.56	4.35	--
4611	Cummins	EPA		1		--	--	--	8,9,10	.80	3.93	--
4612		RTC		1		--	--	--		.65	3.99	--
3661	Cummins	EPA		1		--	--	--	8,9,10	.87	6.13	--
3663		RTC		1		--	--	--		.65	6.32	--
4661	Cummins	EPA		1		--	--	--	8,9,10	.79	6.94	--
4662		RTC		1		--	--	--		.56	6.01	--
4801	Cummins	EPA		1		--	--	--	8,9,10	.86	8.88	--
4802	Cummins	RTC		1		--	--	--		.69	9.06	--
4721	Cummins	EPA		1		--	--	--	8,9,10	.91	6.19	--
4722	Cummins	RTC		1		--	--	--		.68	6.24	--
4773	Cummins	EPA		1		--	--	--	8,9,10	.72	7.91	--
4774	Cummins	RTC		1		--	--	--		.59	7.70	--
4713	Cummins	EPA		1		--	--	--	8,9,10	.98	6.20	--
4714	Cummins	RTC		1		--	--	--		.76	5.73	--

Table 3-3 (cont'd)

Summary of Emissions Data EPA Cycle vs. Real Time Cycle

Engine/ Test Number[a]	Test Lab	Cycle	Number and Type of Tests (CS)	Number and Type of Tests (HS)	Combined Cold/Hot Start: Regressions	Combined Cold/Hot Start: HC (g/BHP-hr)	Combined Cold/Hot Start: NOx (g/BHP-hr)	Combined Cold/Hot Start: Part. (g/BHP-hr)	Hot Start Only: Regressions[b]	Hot Start Only: HC (g/BHP-hr)	Hot Start Only: NOx (g/BHP-hr)	Hot Start Only: Part. (g/BHP-hr)
4831	Cummins	EPA		1		--	--	--	8,9,10	.71	8.04	--
4832	Cummins	RTC		1		--	--	--		.53	8.03	--
3361	Cummins	EPA		1		--	--	--	8,9,10	.60	4.96	--
3364	Cummins	RTC		1		--	--	--		.68	5.16	--
3491	Cummins	EPA		1		--	--	--	8,9,10	.92	3.90	--
3492	Cummins	RTC		1		--	--	--		.75	3.88	--
3981	Cummins	EPA		1		--	--	--	8,9,10	.87	4.33	--
3982	Cummins	RTC		1		--	--	--		.78	4.47	--
4021	Cummins	EPA		1		--	--	--	8,9,10	.87	4.81	--
4022	Cummins	RTC		1		--	--	--		.78	4.91	--
4101	Cummins	EPA		1		--	--	--	8,9,10	.91	4.55	--
4102	Cummins	RTC		1		--	--	--		.82	4.60	--
4123	Cummins	EPA		1		--	--	--	8,9,10	.62	4.81	--
4125	Cummins	RTC		1		--	--	--		.50	5.11	--
4201	Cummins	EPA		1		--	--	--	8,9,10	.46	4.84	--
4202	Cummins	RTC		1		--	--	--		.44	4.62	--
4251	Cummins	EPA		1		--	--	--	8,9,10	.66	3.93	--
4252	Cummins	RTC		1		--	--	--		.56	3.87	--
4271	Cummins	EPA		1		--	--	--	8,9,10	.65	4.23	--
4272	Cummins	RTC		1		--	--	--		.60	4.13	--
4391	Cummins	EPA		1		--	--	--	8,9,10	.69	5.64	--
4392	Cumins	RTC		1		--	--	--		.72	5.61	--

Table 3-3 (cont'd)

Summary of Emissions Data EPA Cycle vs. Real Time Cycle

Engine/ Test Number[a]	Test Lab	Cycle	Number and Type of Tests (CS)	(HS)	Combined Cold/Hot Start Regressions	HC (g/BHP-hr)	NOx (g/BHP-hr)	Part. (g/BHP-hr)	Hot Start Only Regressions[b]	HC (g/BHP-hr)	NOx (g/BHP-hr)	Part. (g/BHP-hr)
4461	Cummins	EPA		1		--	--	--	8,9,10	.52	4.99	--
4685	Cummins	RTC		1		--	--	--		.37	5.08	--
4694	Cummins	EPA		1		--	--	--	8,9,10	.42	4.40	--
4695	Cummins	RTC		1		--	--	--		.37	4.42	--
4697	Cummins	EPA		1		--	--	--	8,9,10	.46	4.73	--
4696	Cummins	RTC		1		--	--	--		.35	4.82	--
4861	Cummins	EPA		1		--	--	--	8,9,10	.53	4.70	--
4864	Cummins	RTC		1		--	--	--		.52	5.06	--
DDA-"A"	DDA	EPA			8,9,11	.57	--	--		.57	--	--
	DDA	RTC				.52	--	--		.52	--	--
DDA-"B"	DDA	EPA			8,9,11	.49	--	--		.48	--	--
	DDA	RTC				.43	--	--		.42	--	--
Mercedes	MB	EPA			8,9,11	1.16	--	--		1.12	--	--
OM362LA	MB	RTC				1.11	--	--		1.09	--	--

[a] Engines are listed per original EPA analysis; more recent data are included at the end of the list.
[b] An explanation of the regressions appears in Table 3-4.
[c] Duplicate engine.
[d] Data changed from hot only to combined per EMA docket submittal, May 13, 1983.
[e] Particulate data not included.
[f] Engine models not specified.
[g] Emissions data derived from plots. Engine models and number and type of tests not specified.
[h] Regression analysis calculated with wrong data (EPA = 1.08, RTC = 1.18).
[i] Changed from .85 to .95 per telephone conversation with IHC on May 16, 1983. The value of .95 was used in Methodologies 4, 5, 8, and 9.
[j] Spurious point; not used in HC regressions.

FIGURE 3-1

EPA Cycle vs. RTC BSHC Emissions

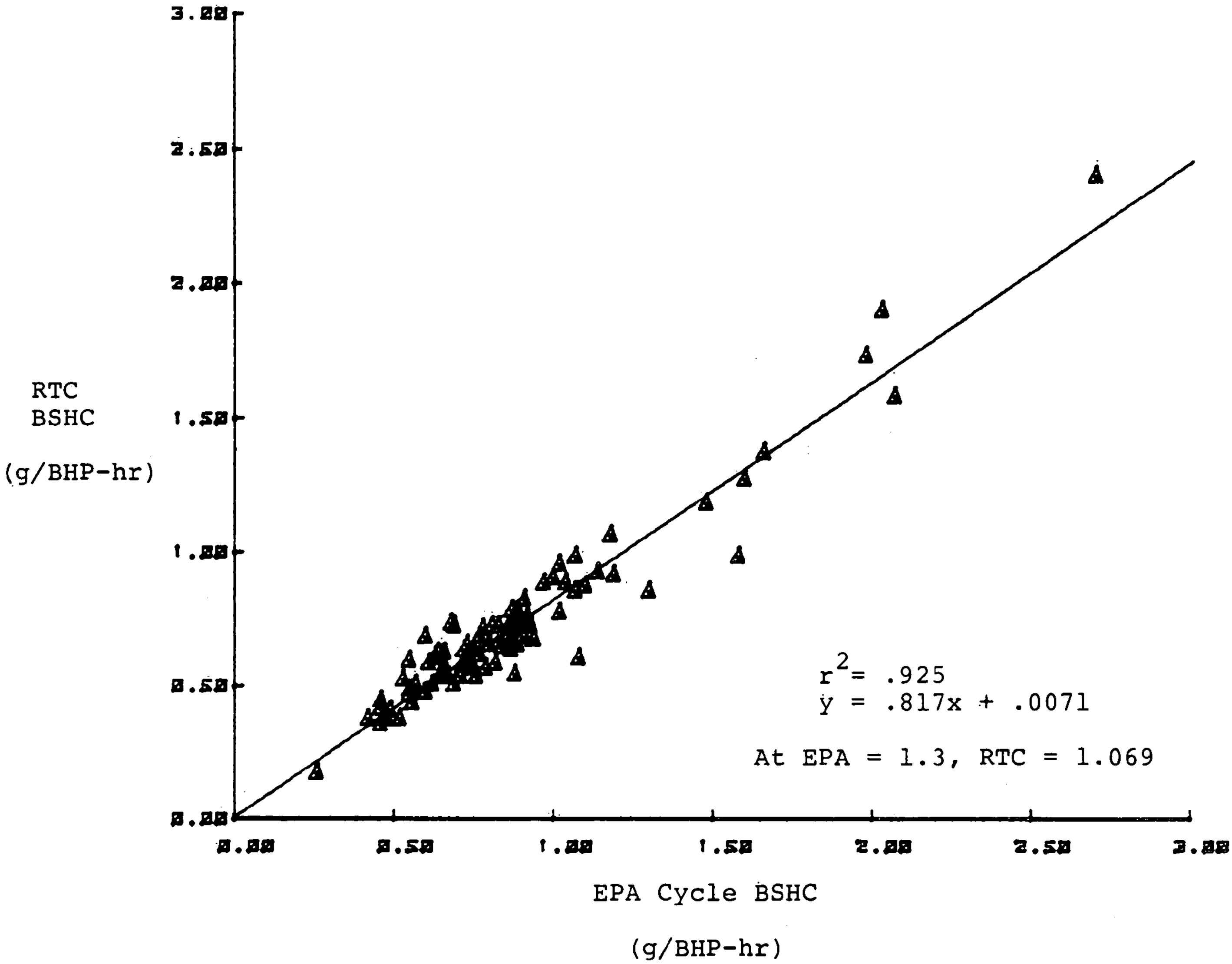


FIGURE 3-2

RTC vs. EPA Cycle BSNOx Emissions

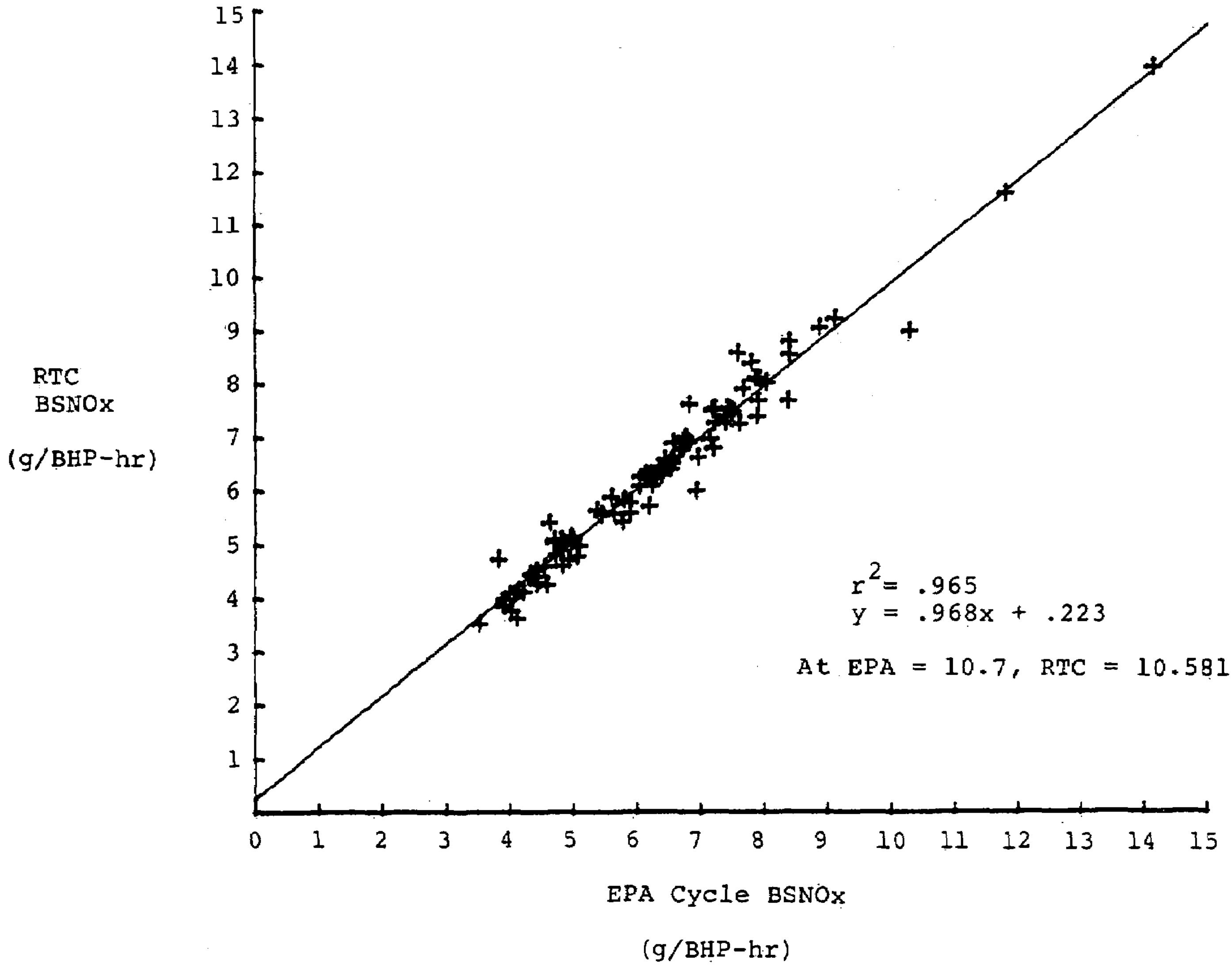
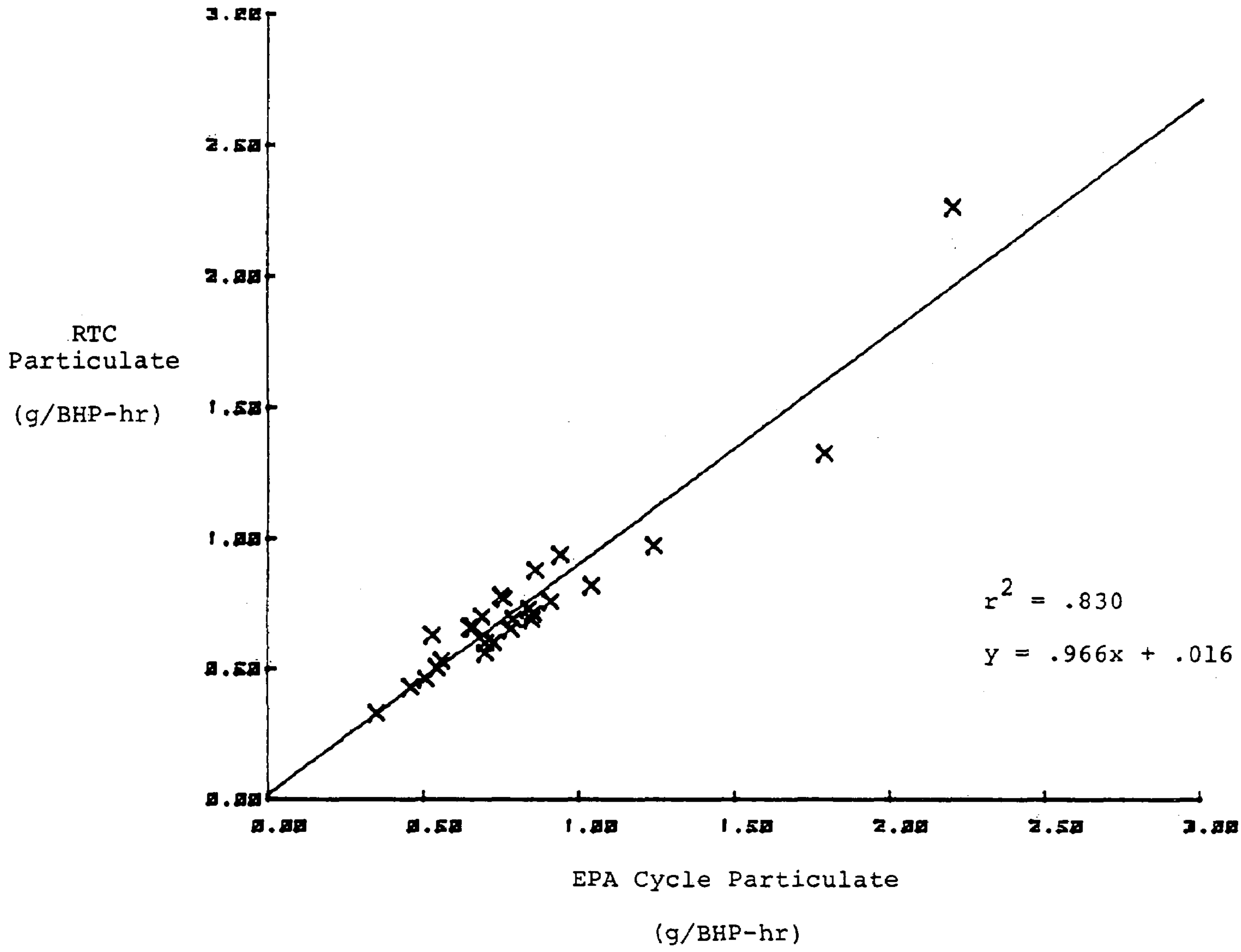


FIGURE 3-3

RTC vs. EPA Cycle Particulate Emissions



Justification for a Standard Adjustment

Given the consistent HC offset between the cycles, EPA believes that there are compelling reasons to adjust the emission standard. EPA cannot agree with EMA's argument that the diesel test cycle should not be linked to the level of emission standards.

First of all, emission standards promulgated on January 21, 1980 were derived using the EPA test cycle. That final rulemaking established the "baseline" against which all subsequent actions must be judged. Test procedures and emission standards are fundamentally related; any significant change to one without the appropriate change to the other represents a net change in the stringency of compliance requirements.

Secondly, the construction of the diesel cycle is not entirely independent from the standard setting process. The gasoline test cycle was used to establish the uncontrolled emission baseline, from which 90 percent reductions were taken to derive the statutory standards. The absolute emission level of the baseline was fundamentally determined by the construction of the gasoline test cycle. Both the EPA gasoline and diesel cycles were composed of the same subcycles in the same sequence (NYNF-LANF-LAF-NYNF). They were both intended to represent characteristic operation of gasoline and diesel trucks over comparable road conditions. This comparability gave EPA confidence that the level of emissions representing the full 90 percent reductions would be achieved by both classes of engines. As noted above, however, the RTC cycle incorporates a NYF segment in lieu of the second NYNF, and some of the operational comparability between the RTC cycle and the gasoline engine baseline is lost. Indeed, had such an operational change been made to the gasoline cycle, EPA is convinced that both the HC baseline and the statutory HC standard would be lower. (Gasoline engine brake specific HC emission rates are substantially lower on the LAF segment than on the LANF segment.) For this reason, the construction of the diesel cycle is not independent of the standard-setting process; comparability in represented road type between gasoline and diesel cycles assures that subsequent emission test results are also comparable.

For the two reasons cited above, EPA does not believe that the specific diesel engine test cycle is independent of either the standard-setting process or the level of the standards. A change in test cycle, therefore, requires an adjustment in emission standards to maintain equivalent stringency.

Standard Adjustment Methodology

To determine equivalently stringent standards for the RTC cycle, EPA evaluated several different methodologies, the results of which are shown in Table 3-4. EPA's first evaluation, distributed for public comment in the summer of 1982, used data from 30 engines/configurations. Twenty-one pairs of the data were combined (cold/hot) results; the remainder were hot-only results. Nine of the engines/configurations are "duplicates," (i.e., they represent the same engines included elsewhere in the data base, but the additional data come from tests performed at different laboratories). This analysis yielded an equivalently stringent HC standard of 1.1 g/BHP-hr (see Table 3-4, Methodology 1).

In early March 1983, Caterpillar recommended another methodology based upon its evaluation of the original data base. Caterpillar concluded that only 16 of the 30 data points used in the EPA evaluation were valid. Caterpillar's evaluation excluded: 1) the hot-only data, and 2) the duplicate engines which were not tested in the laboratory of the engines' manufacturer. Caterpillar excluded the hot-only data claiming that they were "incomplete" tests. (The Federal Test Procedure requires the use of combined cold and hot data.) Caterpillar also excluded duplicate engines from their analysis, claiming that lab-to-lab sensitivity as well as cycle-to-cycle sensitivity would be reflected. After omitting these data points, Caterpillar recommended an RTC equivalent HC standard of 1.2 g/BHP-hr (see Methodology 3, Table 3-4).

EPA then reviewed Caterpillar's analysis to determine if the inclusion of hot-only data and duplicate engines had indeed biased EPA's analysis. (Caterpillar's methodology was accepted and recommended by EMA on May 13, 1983.) EPA staff first contacted the manufacturers and requested all additional data which had been generated since the initial analysis. These data were incorporated into the data base and Caterpillar's (and EMA's) two main concerns were evaluated.

The assertion that the inclusion of hot-only data unduly influenced EPA's analysis was evaluated by directly comparing hot-only data and combined (cold/hot) data in three linear regression analyses (see Methodologies 5, 6, and 7, Table 3-4). The comparisons were done only on engines which had both combined (cold/hot) and hot-only data available. Duplicates were both included and excluded in separate methodologies.

Use of either methodology on identical engines produced insignificant differences in the adjusted emission standards (see Table 3-4). Far more error is induced in the adjusted standard by excluding the hot-only data than including them, primarily because their exclusion reduces the size of the data

Table 3-4

Comparative Methodologies and Results

Methodology	Sample Size	Correlation Coefficient (r^2)	Regression Slope, m	Regression Intercept, b	At EPA = 1.3, EMA =
1. EPA's original analysis using data available in March 1982:	30	.943	.873	-.0302	1.105
2. All available combined data as of March 1982 (duplicates included):	21	.970	.884	-.013	1.134
3. Caterpillar's methodology of early 1983, using EPA's original data (excluding one erroneous point):	16	.993	.920	-.039	1.156
4. Caterpillar's exact methodology of early 1983 (EPA's original data with one erroneous point):	16	.983	.922	-.029	1.170

Table 3-4 (cont'd)

Cold/Hot Versus Hot-Only Comparison

Methodology	Sample Size	Correlation Coefficient (r^2)	Regression Slope, m	Regression Intercept, b	At EPA = 1.3, EMA =
5. Direct comparison of combined cold/hot data vs. hot-only data (duplicates included):					
a. Combined data	17	.974	.905	-.035	1.142
b. Hot-only data	17	.974	.883	+.000	1.148
6. Same as 5, but all duplicate engines excluded if "home" lab has both combined and hot-only data:					
a. Combined data	15	.995	.922	-.034	1.164
b. Hot-only data	15	.994	.897	+.002	1.167
7. Same as 5, but only "home" lab data used (all duplicates excluded):					
a. Combined data	13	.996	.928	-.047	1.160
b. Hot-only data	13	.995	.899	-.003	1.166

Table 3-4 (cont'd)

Comparative Methodologies and Results

Methodology	Sample Size	Correlation Coefficient (r^2)	Regression Slope, m	Regression Intercept, b	At EPA = 1.37, EMA =
8. All combined data, plus hot-only data for engines where combined data is not available (duplicates included). For all data available by June 1, 1983. (EPA's recommended methodology):	99	.925	.817	.007	1.069
9. Same as Methodology 8 (EPA's recommended methodology), but duplicates excluded (home lab data only):	90	.923	.826	-.0018	1.072
10. EPA's recommended methodology, but "sales-weighted," using each manufacturer's percentage of total sales, as shown in Table 3-5:	162	.920	.810	.037	1.09
11. EMA's proposed methodology (May, 1983), excluding hot-only data and duplicates:	23	.988	.901	-.018	1.153

base by almost 70 percent, including the exclusion of all but one engine of the major manufacturer (Cummins Engine Company). The importance of the additional data can be seen in Figure 3-4, in which RTC HC equivalent emissions are plotted as a function of sample size. As the data base increases, the adjusted standard converges on 1.1 g/BHP-hr. Again, this may not so much be an effect of sample size, but more an effect of the inclusion of Cummins's engines in a more representative number. In short, the most accurate representation of the difference between the test cycles is derived from the larger data base; the starting condition of the engine has been demonstrated to be unimportant.

The resulting equivalently stringent HC standard using all available data (Methodology 8) is 1.1 g/BHP-hr. Note that Methodology 9 excluded duplicate engines but included hot-only data; the impact of the duplicate engines on the magnitude of the adjustment is insignificant once hot-only data is included.

As a final evaluation of the sensitivity of the standard adjustment to methodology, and to ensure that one manufacturer's data didn't bias the adjustment, EPA also performed a "sales-weighted" analysis (see Methodology 10). Table 3-5 shows each manufacturer's percentage of total sales and the "weight," (i.e., the number of times added to the regression) of each manufacturer's engines used in the analysis. Again, the equivalent HC emission standard was found to be 1.1 g/BHP-hr.

Based upon the insensitivity of the standard adjustment to engine starting condition, the best and most representative data base is that which includes all of the available data. The emission standards for the RTC are derived by substituting the EPA standards in linear regression equations derived from the most representative data base. Using the regression equations from Figures 3-1 and 3-2 (derived using Methodology 8), and EPA standards of 1.3 g/BHP-hr HC and 10.7 g/BHP-hr nitrogen oxides (NOx), the respective standards for the RTC would be:

HC: 1.1 g/BHP-hr NOx: 10.6 g/BHP-hr

Cycle Selection

In their final comments, the EMA recommended that either the RTC cycle be adopted with a HC standard of 1.2 g/BHP-hr, or the EPA cycle be retained with the existing 1.3 g/BHP-hr standard. In any case, EMA argued, only a single cycle should be set in place.

Table 3-5

"Sales Weighted" Regression Analysis

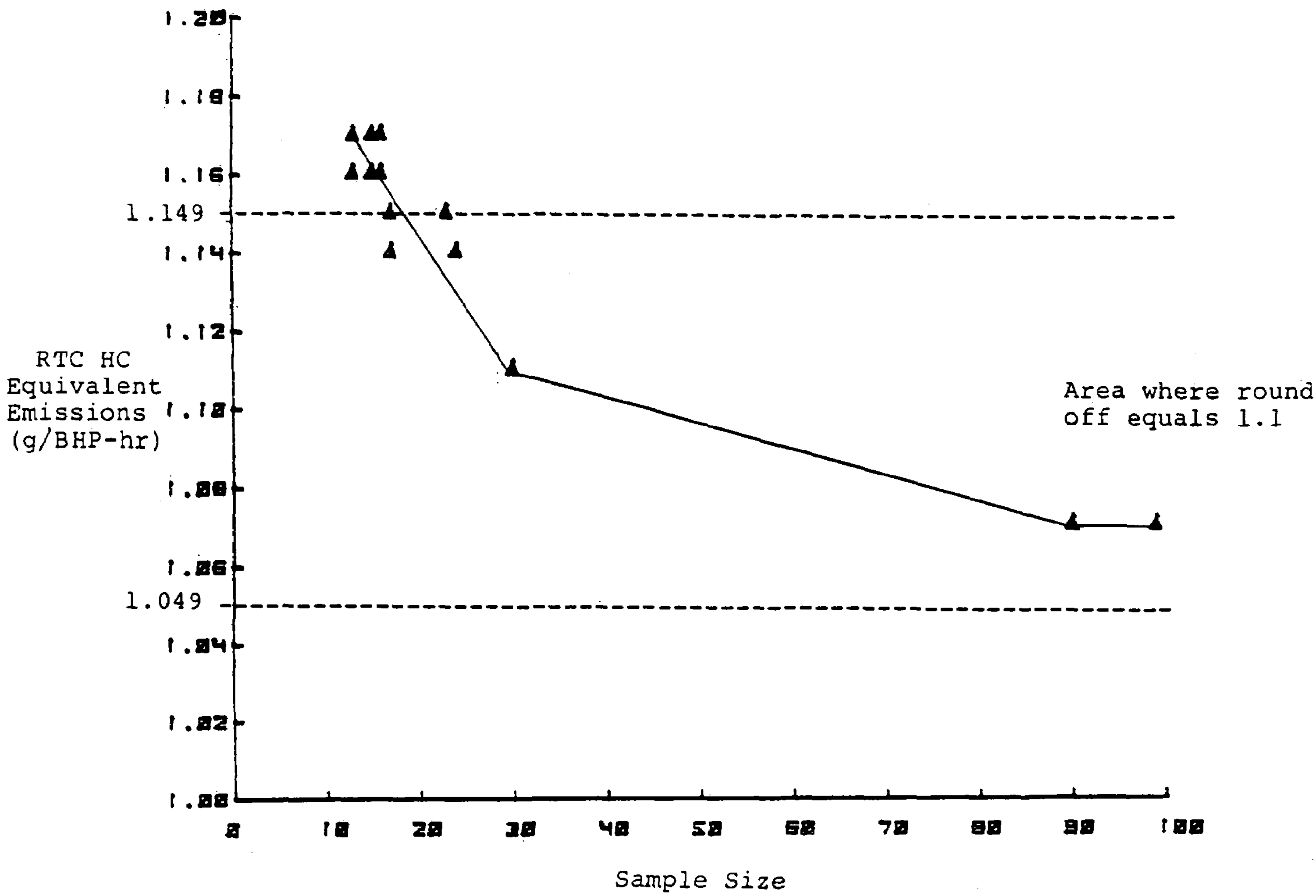
Existing Data:

Number of Engines		Factor	New Data Base	Percent of Total
10 Caterpillar	X	2	20	12.4
66 Cummins	X	1	66	40.7
5 DDA	X	8	40	24.7
9 IHC	X	2	18	11.1
6 Mack	X	3	18	11.1
		Total:	162	100%

* These percentages correspond roughly to 1979 market shares, based upon actual production volumes.

Figure 3-4

Sample Size vs. RTC HC Equivalent Emissions



With respect to the number of test cycles, EPA concurs with EMA's rationale for a single cycle. The use of more than one cycle should be avoided when possible, since it can create unnecessary testing and can add unwarranted complexity to the certification process. With respect to the representativeness of the RTC cycle, EPA considers the development work done by Caterpillar to be technically sound and to have produced a thoroughly valid and representative test cycle. On the other hand, the strong correlation between both cycles increases EPA's already strong confidence in the ability of its own test cycle to predict in-use emission reductions (see Appendix, Chapter 4 of the Transient Test Study).

The issue then boils down to the adjustment of emission standards. Given the observed difference in emissions between test cycles, and given that statutory standards with the existing cycle have already been promulgated, there is no alternative but to adjust the standards for a change in test procedure. If the new test cycle represented an increase in stringency at the same numerical standard, instead of the decrease in stringency seen with the RTC, a standard adjustment would likewise be appropriate. With respect to the magnitude of the adjustment, EPA has been consistently open in presenting its methodologies and results, and has been open to industry's comments. EPA's analysis yields a greater HC adjustment than EMA's recommended methodology, but in EPA's judgment represents a more accurate characterization of the average cycle-to-cycle relationship for the average engine.

EPA has attempted, over time, to reach a consensus with the EMA on the technical issue of the test cycle. EMA's final recommendation to EPA is to promulgate a single cycle, either the EPA cycle at 1.3 g/BHP-hr HC or the RTC cycle at 1.20 g/BHP-hr. For the reasons cited above, EPA can promulgate the RTC cycle with an HC standard of 1.1 g/BHP-hr.

Conclusion

The EPA cycle will be retained as the single driving cycle for the certification of 1984 and later model year HDDEs, in conjunction with the 1.3 g/BHP-hr HC and the 10.7 g/BHP-hr NOx standards.

B. The MVMA Cycle for Heavy-Duty Gasoline Engines

Summary of the Issue

The Motor Vehicle Manufacturers Association (MVMA) has developed an alternative heavy-duty gasoline engine (HDGE) driving cycle. The MVMA cycle was developed because of its concern about the representativeness of the EPA cycle.

Summary of Comments

MVMA and member manufacturers have on several occasions submitted specific recommendations for the MVMA cycle. A brief synopsis of events is again appropriate.

In earlier submissions to EPA, Ford Motor Company (Ford), General Motors Corporation (GM), and the MVMA recommended that EPA replace its own test cycle with the MVMA cycle. This position was reiterated in comments made to the Agency in April of 1982.

EPA's original evaluation (see Appendix, Chapter 6 of the Transient Test Study) of the MVMA test cycle was distributed for public comment in the early summer of 1982. That analysis drew several conclusions about the MVMA cycle. First of all, the MVMA cycle was shown to correlate well with the EPA cycle. Secondly, both HC and CO emissions measured over the MVMA cycle were less than those measured on the EPA cycle, and an adjustment of emissions standards was recommended. Finally, the available data base comparing both cycles was small, and given the undocumented nature of the MVMA cycle's generation, EPA was cautious in its recommendations. More comparative testing between cycles was recommended; EPA judged on the basis of available evidence that the MVMA cycle might perhaps be acceptable as a test option.

Industry's reaction to EPA's analysis initially disputed the need for an adjustment of emission standards, but also agreed with the need for more testing between cycles. The need for more testing was especially clear at the level of the statutory HC and CO standards. No comparative data existed at these low emission levels, creating substantial uncertainty as to the proper adjustments to the statutory standards.

Since then, EPA and the manufacturers have cooperated in generating more test data. The original data base of 14 engines/engine configurations has been expanded to 35. The new data base includes engines of all technologies, ranging from uncontrolled 1969 baseline engines to catalyst-equipped 1985 prototypes. (The analysis of this data base is presented below.)

Both EPA and the industry evaluated the new emission data. In letters to EPA dated on June 10 and June 16, 1983, the MVMA recommended provision of the MVMA cycle as a test option (contrary to earlier recommendations). The industry agreed that a standard adjustment was appropriate, and a specific standard adjustment methodology was recommended, whereby the data base would be split into catalyst and non-catalyst groupings, and emission standards would be adjusted from analysis of the appropriate data base.

Analysis of Comments

In this analysis, we address the construction, representativeness, and relative stringency of the MVMA cycle. Methodologies for emission standards adjustment are discussed, as is the selection of a test cycle for certification testing.

Cycle Development

The MVMA HDGE driving cycle was developed because of industry concerns that the EPA cycle was inadequate in the following two areas:

1. It was not representative of real world truck operation.

2. The irregular nature of the cycle could create interlaboratory correlation problems.

In an attempt to alleviate some of these concerns, MVMA modified the EPA cycle to obtain a driving cycle which they felt was more representative and more acceptable. MVMA established four basic objectives for constructing the modified test cycle. The modified cycle had to:

1. Maintain the general character of the EPA cycle.

2. Improve the relationship between simultaneous speed, power, and acceleration.

3. Reduce momentary speed excursions.

4. Reduce excessive throttle manipulations.

To accomplish these objectives, the cycle was simply examined on a second-by-second basis; using engineering judgment, the speed and torque specifications were revised where deemed appropriate. The resulting driving cycle was a smoothed version of the EPA cycle with a revised synchronization between speed and torque commands. Technical justification for specific cycle changes were not submitted or documented by MVMA.

Statistical Analysis

A comparison of overall statistical parameters from the MVMA cycle, EPA cycle, and the CAPE-21 data base is listed in Table 3-6. The CAPE-21 statistics are included for comparison purposes, although the MVMA cycle was not directly derived from the CAPE-21 data base.

Table 3-6
Cycle Statistics: MVMA Cycle, EPA Cycle, CAPE-21 Data Base

Parameter	MVMA	EPA	PE-21
Torque			
Mean (%)	37	36	34
Percent of Cycle Time			
Acceleration (%)	15	17	15
Deceleration (%)	19	20	16
Cruise (%)	28	26	28
Motor (%)	9	10	13
Idle (%)	28	27	28
RPM			
Mean (%)	31	30	31
Percent of Cycle Time			
Acceleration (%)	20	24	20
Deceleration (%)	26	21	26
Cruise (%)	26	23	26
Idle (%)	28	31	28

As can be seen from the table, the EPA cycle and MVMA cycle are very similar statistically. There are no major discrepancies, which is to be expected since the MVMA driving cycle is directly derived from the EPA cycle. However, data from engine tests indicate total engine work (BHP-hr) over the MVMA cycle is about 10 percent higher than on the EPA cycle. This increase in cycle work is attributable to the resynchronization of the speed and torque commands. The MVMA cycle is also less transient than the EPA cycle. The speed and torque sequences are smoother, and numbers of torque accelerations have been completely eliminated, thereby reducing the number of throttle position changes. (This reduces accelerator pump operation and transient fuel enrichment.)

The MVMA cycle is statistically similar to the EPA cycle, but not operationally identical.

Test Cycle Correlation Analysis

EPA, Ford, and GM have now tested 35 gasoline engine configurations to compare the MVMA and the EPA cycle. Both catalyst and non-catalyst configurations have been tested, as have engines at all levels of emission control. (The emission data from these tests are summarized in Table 3-7.)

Excellent statistical correlations were observed between the MVMA cycle and the EPA cycle. The data were split into non-catalyst and catalyst sets, on which linear regression analyses were performed. For non-catalyst emissions of HC and CO, coefficients of determination (r^2) values were found to be .972 and .987, respectively. The r^2 values for catalyst emissions of HC and CO were .915 and .975, respectively. For the entire data base, the r^2 value for NOx emissions was .974. The above data indicates that in all cases, the correlation between the test cycles is strong.

In both sets of data, however, MVMA cycle emissions are consistently less than those measured on the EPA cycle. These differences are explainable by the operational differences between the cycles, (i.e., the MVMA cycle is smoother, and that the speed and torque commands follow each other more closely on the MVMA cycle resulting in an increase in integrated power-hour). These changes are illustrated graphically in Figure 3-5 where the same characteristic sections from both test cycles have been overlaid. The decrease in the transience of the MVMA cycle results in less movement of the engine accelerator pump, which would be expected to result in lower HC and CO emissions. The rephasing of the speed and torque commands results in different modes of engine operation on the two test cycles, with fewer events at both lower speed and load on the MVMA cycle. The observed increase in power-hour over the MVMA cycle may also explain the decrease in the brake

Table 3-7

MVMA Transient Test Cycle Adjustment Analysis
Emissions Data: g/BHP-hr

		EPA Cycle				MVMA Cycle				
No.	Test Facility	Tests	HC	CO	NOx	Tests	HC	CO	NOx	Comments
1	EPA	3C/5H	6.12	118.4	6.54	2C/5H	4.72	109.4	6.38	1969 GM 4.8L (292 CID) - original data base
2	EPA	2C/4H	7.64	126.6	7.74	2C/4H	6.49	125.0	7.50	1969 Ford 4.9L (300 CID) - original data base
3	EPA	2C/5H	8.14	135.5	4.43	2C/5H	7.71	143.2	4.22	1969 GM 5.8L (350 CID) - orignial data base
4	Ford	2C/2H	2.86	28.4	8.04	1C/1H	2.40	21.7	8.75	1985 prototype Ford 4.9L (300 CID) - original data base
5	Ford	1C/1H	2.36	28.9	7.42	1C/1H	1.50	27.8	6.67	1985 prototype Ford 6.1L (370 CID) - original data base
6	Ford	2C/4H	2.46	30.5	8.29	2C/6H	1.59	25.7	8.01	1985 prototype Ford 6.1L (370 CID) - original data base
7	Ford	1C/3H	3.28	31.3	8.55	1C/3H	1.81	27.7	8.77	1985 portotype Ford 6.1L (370 CID) - original data base
8	Ford	1C/1H	2.34	30.6	8.17	1C/1H	1.48	25.5	8.04	1985 prototype Ford 6.1L (380 CID) - original data base
9	GM	1C/1H	1.28	47.9	5.06	1C/1H	1.44	52.4	4.91	1981 GM 7.5L (454 CID) - original data base
10	GM	1C/1H	3.12	98.7	5.48	1C/1H	2.89	100.4	4.25	Ibid: less controls - original data base

Table 3-7 (cont'd)

MVMA Transient Test Cycle Adjustment Analysis
Emissions Data: g/BHP-hr

No.	Test Facility	EPA Cycle Tests	EPA Cycle HC	EPA Cycle CO	EPA Cycle NOx	MVMA Cycle Tests	MVMA Cycle HC	MVMA Cycle CO	MVMA Cycle NOx	Comments
11	GM	1C/1H	7.45	63.4	6.22	1C/1H	5.85	52.9	6.47	1981 GM 7.0L (427 CID) - original data base
12	GM	1C/1H	10.06	129.6	5.67	1C/1H	8.51	116.0	5.93	Ibid: less controls - original data base
13	GM	1C/1H	3.33	26.7	8.13	1C/1H	2.70	26.3	8.11	1981 GM 4.8 (292 CID) - original data base
14	GM	1H	1.66	12.3	8.93	1H	1.08	10.8	8.89	Ibid: less controls - original data base
15	Ford	4C/4H	3.21	34.6	8.09	4C/4H	2.02	27.1	8.11	1983 modified Ford 6.1L (370 CID) - correlation program
16	EPA	4C/4H	4.05	30.8	7.04	4C/4H	3.30	30.0	7.14	Ibid
17	Ford	2C/2H	1.75	36.9	7.32	2C/2H	1.46	34.1	7.48	1983 modified GM 5.8L (350 CID) - correlation program
18	GM	4C/4H	2.23	33.3	7.90	3C/3H	1.79	34.1	7.99	Ibid
19	Ford	2C/2H	1.84	35.3	5.56	3C/3H	1.28	29.8	5.09	1985 prototype Ford 7.5L (454 CID)
20	Ford	2C/2H	1.70	19.7	5.44	1C/1H	1.20	18.2	4.77	Ibid
21	Ford	4C/4H	0.47	18.2	5.43	3C/3H	0.37	16.3	4.86	1985 prototype Ford 7.5L (454 CID): 2 150 in^3 COC LDT new catalysts
22	GM	2H	0.41	55.5	1.70	2H	0.41	60.3	1.76	1983 LDT GM 5.8L (350 CID): 260 in^3 COC new pelletized catalyst

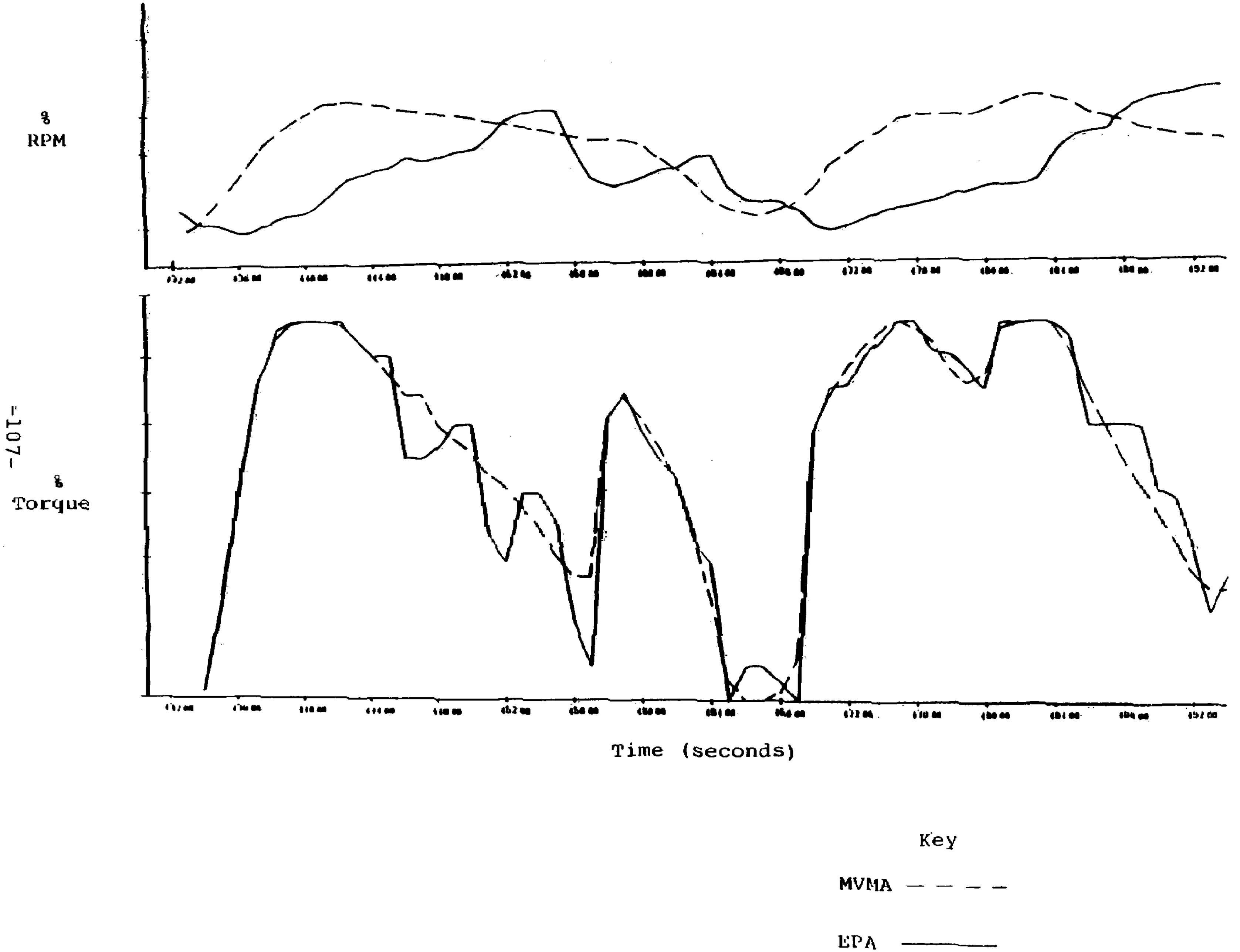
Table 3-7 (cont'd)

MVMA Transient Test Cycle Adjustment Analysis
Emissions Data: g/BHP-hr

No.	Test Facility	EPA Cycle Tests	HC	CO	NOx	MVMA Cycle Tests	HC	CO	NOx	Comments
23	EPA	3C/3H	0.52	40.8	2.97	3C/3H	0.48	45.0	2.63	1982 LDV-S/W GM 5.0L (305 CID): 260 in^3 COC pelletized catalyst
24	SwRI	2C/2H	0.39	5.6	2.50	2C/2H	0.34	7.3	2.30	1975 5.7L (350 CID): COC/TWC pelletized catalyst
25	EPA	2C/2H	0.78	72.6	.19	2C/2H	.79	75.3	1.07	1982 LDT Ford 5.0L (302 CID): 128 in^3 COC/TWC system
26	EPA	1C/1H	4.15	105.5	3.84	1C/1H	2.59	106.0	3.90	Ibid: without catalysts
27	EPA	2C/2H	2.42	94.5	1.80	2C/2H	1.88	83.8	1.90	Ibid: catalyst system moved to location behind muffler
28	EPA	5H	4.04	153.6	5.51	2H	3.57	164.7	4.60	1981 LDV GM 5.8L (350 CID) TWC system: tested without catalyst
29	GM	1C/1H	.53	5.6	4.44	1C/1H	.41	4.7	4.54	Chevy 350 HD prototype: 2 260 in^3 COC pellet catalysts
30	EPA	2C/2H	.89	20.0	9.54	2C/2H	.61	18.7	9.18	1985 prototype Ford 7.5L (454 CID): 2 150 in^3 COC LDT new catalysts
31	EPA	1C/2H	2.49	33.3	8.88	1C/2H	1.95	30.9	9.21	Ibid: without catalysts
32	EPA	2C/2H	1.68	59.4	2.62	2C/2H	1.43	55.7	2.72	1982 LDT Ford 5.0L (454 CID): 128 in^3 COC catalyst
33	EPA	1C/2H	4.74	89.7	4.18	1C/2H	3.84	87.7	3.97	Ibid: without catalyst

Figure 3-5

MVMA Cycle and EPA Cycle Comparison



specific emissions (i.e., more emissions divided by increased output work). Changing the engine speed at which motoring (defined as -10 percent maximum engine torque) occurs would certainly create HC emission differences between the cycles. Smoothing of the MVMA's cold start cycle may also yield lower HC emissions, especially for catalyst-equipped engines.

In summary, the MVMA cycle does not yield emissions equivalent to the EPA driving cycle; it is not equivalently stringent at the same numerical emission standards for HC and CO. The MVMA cycle does, however, correlate well with the EPA cycle for a wide variety of engines. This strong correlation implies that there is no advantage in using one cycle over the other to predict in-use emission reductions.

Standard Adjustment Methodology

EPA's review of the available data indicates that different correlations exist between the test cycles, depending upon the technology applied to the engine. Specifically, the relationship between the test cycles is affected by the presence of a catalyst, especially for HC. Given this fact, we also note the fact that the standards to be adjusted, 1.3/15.5 and 2.5/40.0, represent 100 percent catalyst and 100 percent non-catalyst technologies, respectively. The most rigorous technical approach for adjusting the emission standards would therefore be to split the data base into catalyst and non-catalyst groupings. The MVMA cycle-based non-catalyst standards would be obtained from an analysis of only non-catalyst data. Similarly, the MVMA cycle-based catalyst standards would be obtained from only the catalyst data.

The non-catalyst data and the resulting linear regression equations for HC and CO are presented in Figures 3-6 and 3-7. The non-catalyst analysis is straightforward, and uses all available non-catalyst data. However, the derivation of appropriate linear regressions for the catalyst data base cannot be made without first exercising some engineering judgment. Emissions observed on these catalyst-equipped engines lay over a very wide range. (Several of the engines were light-duty truck engines, with catalysts and air injection systems ill-designed to control CO emissions over the heavy-duty test.) Some data lay far enough outside of the range expected for HDGEs that they should be judged unrepresentative and excluded from analysis. In addition, excluding all unrepresentatively high CO data for catalyst-equipped engines leaves only six representative data pairs. This is a data base whose small size may raise concern as to the accuracy of the derived MVMA cycle-based standard.

All in all, five data pairs should be discarded from the CO analysis as unrepresentative. (Each of the five lies above

Figure 3-6

EPA Cycle vs. MVMA Cycle
BSHC Non-Catalyst Emissions

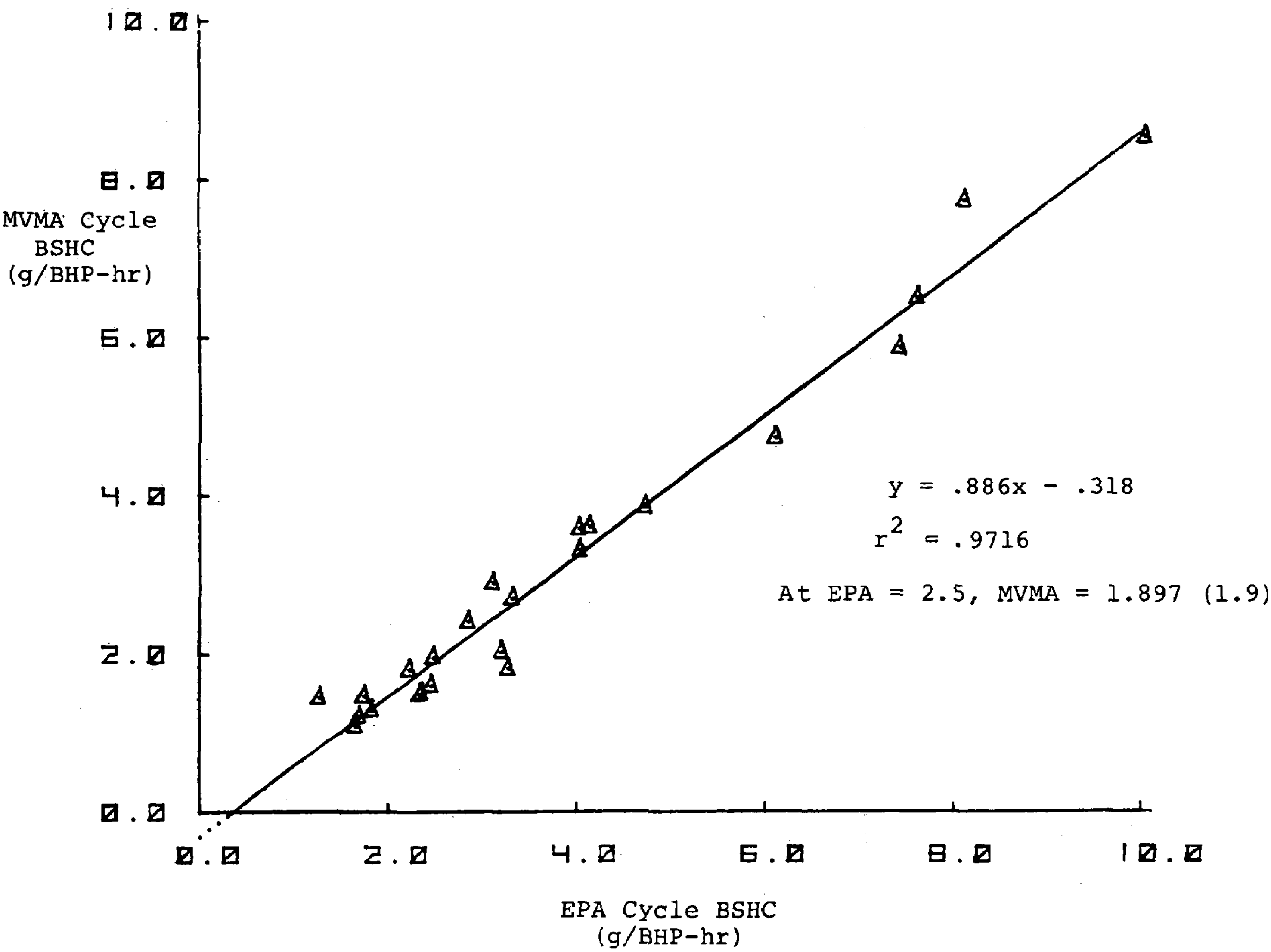
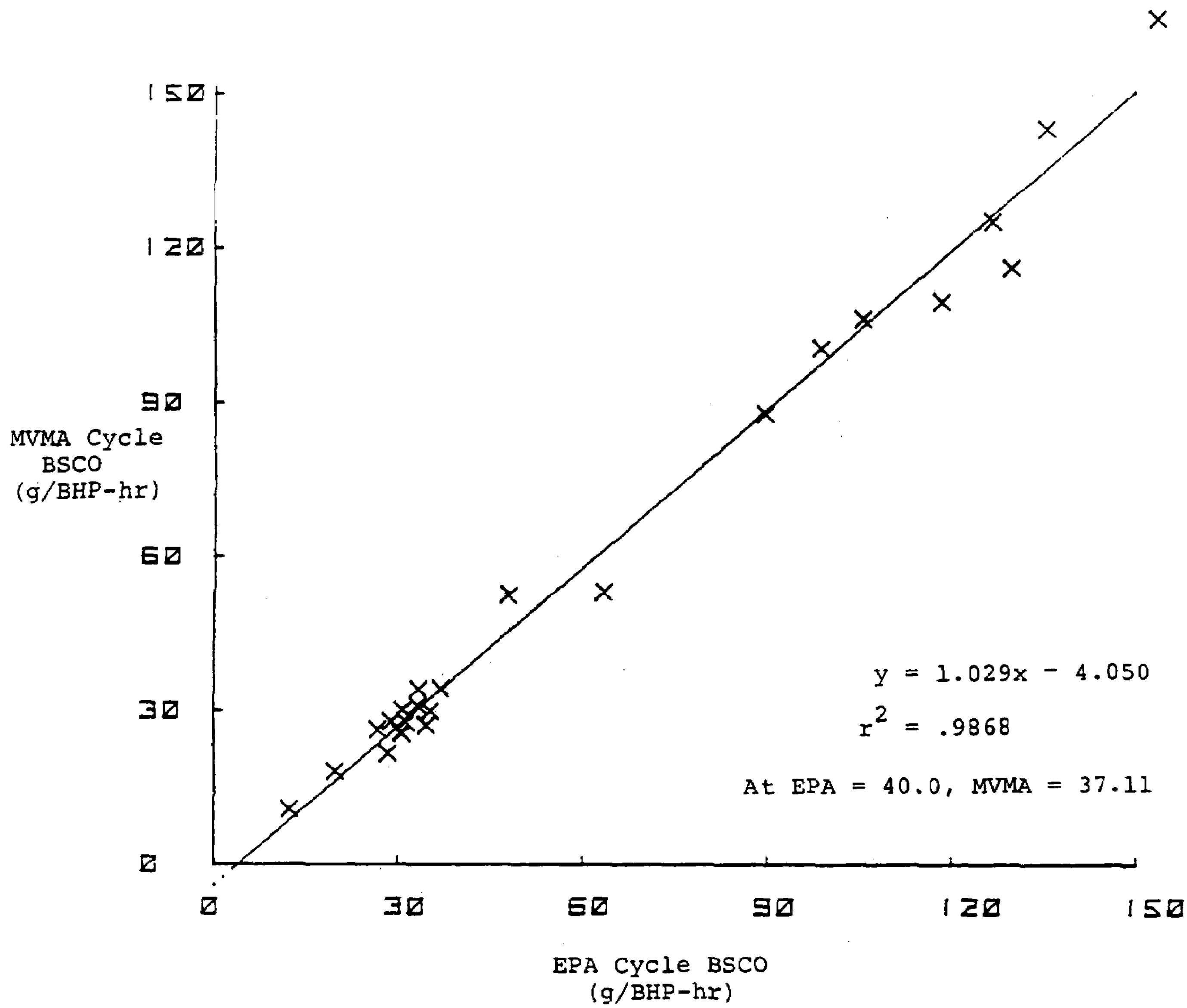


Figure 3-7

EPA Cycle vs. MVMA Cycle
BSCO Non-Catalyst Emissions



40.0 g/BHP-hr, well beyond the range of the 15.5 g/BHP-hr standard.) Similarly, one data pair should be discarded from the HC analysis. (This data was taken by EPA with the catalyst relocated behind the muffler in an attempt to characterize the effects of catalyst location. The HC emissions were well above the 1.3 g/BHP-hr level, and the engine is not representative of a typical catalyst-equipped engine.) Using the remaining data, the catalyst regression equations for HC and CO are presented in Figures 3-8 and 3-9.

Finally, for the adjustment of the NOx standard of 10.7 g/BHP-hr, all 35 data pairs were used. NOx emissions are not significantly affected by the presence of a catalyst, and it is not necessary to segregate the data base. This analysis and its accompanying regression equation are presented in Figure 3-10.

Based upon the 1985 non-catalyst EPA cycle-based standards of 2.5 g/BHP-hr HC, 40.0 g/BHP-hr CO, 10.7 g/BHP-hr NOx, the 1987 EPA cycle-based standards of 1.3/15.5/10.7, and the derived regression equations, equivalently stringent standards for the MVMA cycle are as follows:

	HC (g/BHP-hr)	CO (g/BHP-hr)	NOX (g/BHP-hr)
1985 MVMA Standards (non-catalyst)	1.9	37.1	10.6
1987 MVMA Standards (catalyst)	1.1	14.4	10.6

EPA is confident in the accuracy of the derived adjustments for both HC standards (catalyst and non-catalyst), both NOx standards, and the non-catalyst CO standard. EPA was initially concerned, however, about the accuracy of the adjustment for the 1987 CO standard because of the small sample. Upon reviewing all data, however, EPA is reasonably confident in its accuracy. For six data pairs included in this analysis, the offset between cycles is fairly consistent; the ratios of MVMA cycle CO to EPA cycle CO exhibit a coefficient of variation of 17.3 percent, but only 4.4 percent if the single outlier is excluded. In other words, the offset is repeatable. More significantly, the ratio of the adjusted MVMA cycle-based standard to the EPA cycle-based standard for catalyst engines is virtually identical to that observed in the adjustment of the non-catalyst standard (14.4/15.5 equals .929, whereas 37.1/40.0 equals .928.) Assuming substantially similar test cycles, and assuming that the catalyst operates at a constant oxidation efficiency over the test cycles, this observation is to be expected. Note that the same observation

Figure 3-8

EPA Cycle vs. MVMA Cycle
BSHC Catalyst Emissions

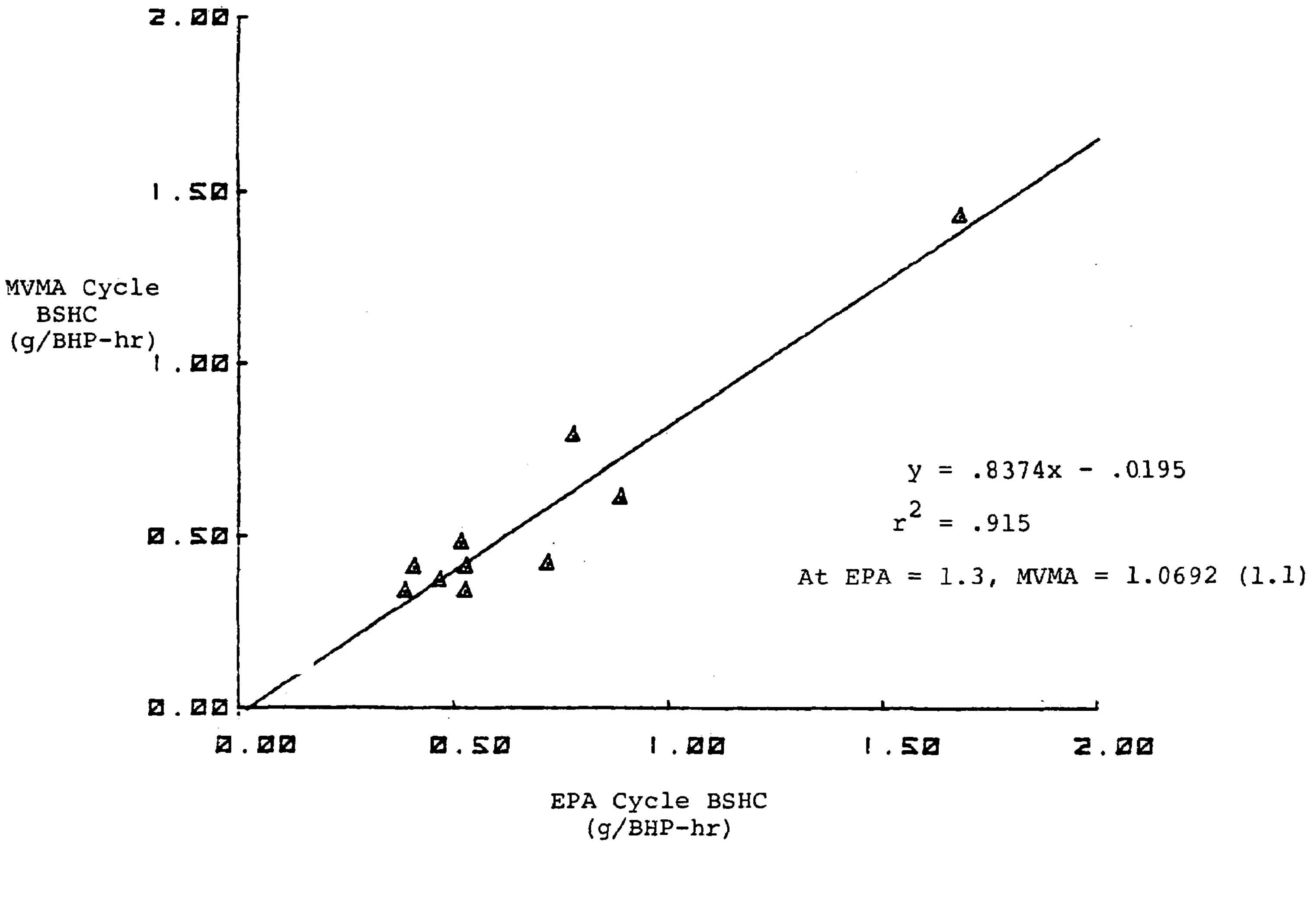


Figure 3-9

EPA Cycle vs. MVMA Cycle
BSCO Catalyst Emissions

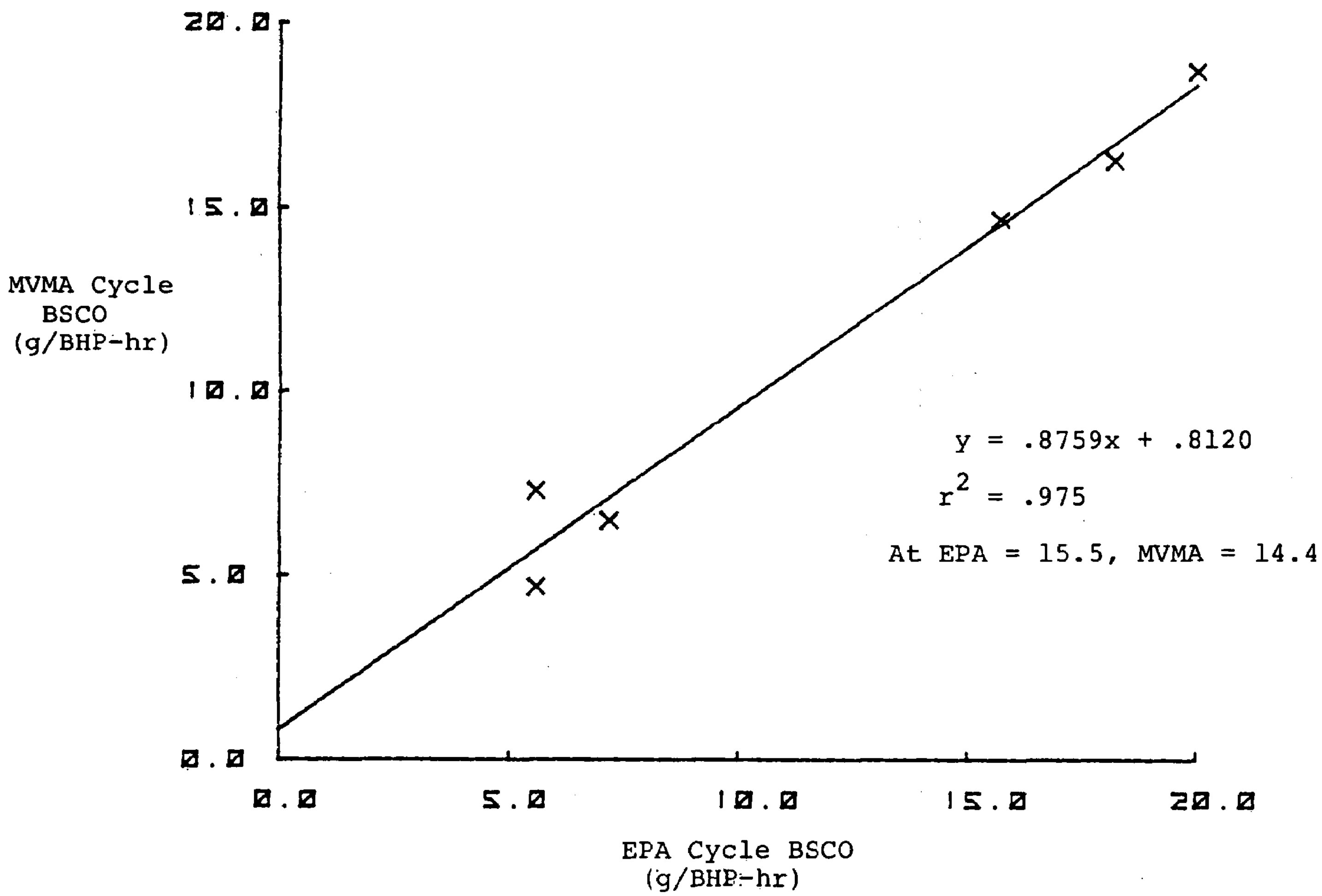
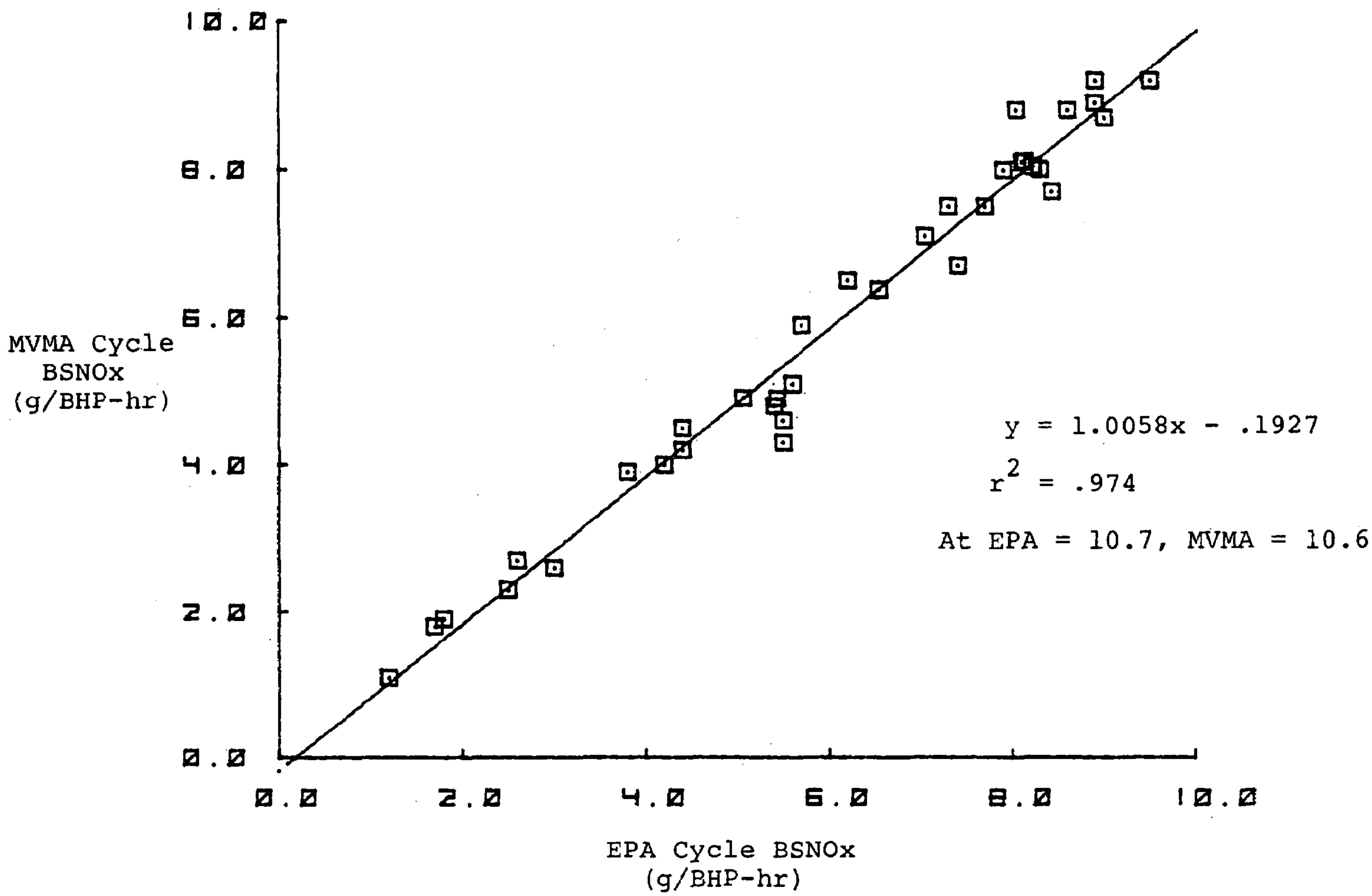


Figure 3-10

EPA Cycle vs. MVMA Cycle
BSNOx (Catalyst and Non-Catalyst)



is not true for HC: 1.1/1.3 equals .846, whereas 1.9/2.5 equals .760. This is also to be expected, however, because the catalyst does not maintain a constant efficiency over the test cycle for HC oxidation. The cold start produces the majority of HC emissions on catalyst-equipped engines; the HC offset between the MVMA and EPA cycles on catalyst-equipped engines is primarily attributable to the offset in HC emissions before catalyst light-off. (HC emissions on either cycle after light-off are virtually eliminated by the catalyst.) Primarily for this reason, the degree of HC adjustment between cycles differs between catalyst and non-catalyst engines. Most of the CO emissions, however, for both catalyst and non-catalyst engines come from high-power, warmed-up operating modes. For this reason, EPA believes that its assumption of constant catalyst efficiency in evaluating the CO adjustment is valid, and that the derived MVMA cycle-based statutory CO standard is correct. Any error in the adjustment of the statutory CO standard is likely to be small.

Test Cycle Selection

For the reasons discussed in the RTC analysis, EPA prefers the use of a single cycle for certification. MVMA, however, recommended that its cycle be adopted as an option for 1985, primarily because different member manufacturers have conducted development work on different cycles. Selection of a single cycle for 1985 may penalize a manufacturer who has used the rejected cycle for all development work. In a letter to EPA dated June 16, 1983, MVMA was unable to identify conditions under which it would accept a single cycle (unlike EMA's final recommendation on the EPA/RTC cycle selection). MVMA also did not specifically recommend which cycle should eventually be chosen as the single certification cycle beyond 1985, although it agreed with EPA that a single cycle should eventually be selected.

EPA can appreciate the position a manufacturer would find itself in if the test cycle on which all its development work was based was suddenly eliminated. For this reason, EPA can accept the use of an optional test cycle in 1985, and the Agency will conduct all its confirmatory testing, SEA testing, etc., with the specific cycle on which a manufacturer certifies, provided that the manufacturer certifies its entire product line on the same cycle. (Required use of a single cycle by a manufacturer for all its engines will eliminate the potential for gamesmanship by selecting the "best" cycle for a specific engine family.) Under these conditions, EPA finds the use of the MVMA cycle as an optional procedure for 1985 to be acceptable.

On the other hand, EPA cannot accept the indefinite provision of two test cycles. Our analyses indicate that either cycle would be acceptable, provided that the emission standards were appropriately adjusted. For this reason, and in the interest of reaching a technical accommodation with the industry, EPA has no objection to adopting the MVMA cycle as the official EPA certification test cycle. It is EPA's judgment that the MVMA cycle is preferred by the industry. This adoption is most reasonably made in the 1987 model year, when the next major recertification of HDGEs occurs.

Conclusions

1. Both the EPA and MVMA test cycles will be permitted for certification in 1985 and 1986; optional use of either cycle will be permitted, provided that any single manufacturer certifies all its engines on the same test. Similarly, all confirmatory and other regulatory testing will be conducted on the same cycle on which the manufacturer originally certified.

2. After 1986, all certification and running change testing (except carryover for non-catalyst engines previously certified on the EPA cycle) will be conducted on the MVMA cycle.

3. The following emission standards, as derived by this analysis, will be used:

		BSHC (g/BHP-hr)	BSCO (g/BHP-hr)	BSNOx (g/BHP-hr)
1985:	EPA Cycle	2.5	40.0	10.7
	MVMA Cycle	1.9	37.1	10.6
1987:	MVMA Cycle	1.1	14.4	10.6

References

1. Derived from Comments Submitted to EPA Public Docket No. A-81-20.

2. Derived from Comments Submitted to EPA Public Docket No. A-81-11.

3. "Evaluation of the Federal Test Procedure for Heavy-Duty Diesel Engines for 1984 and the Development of the Real Time Test Cycle," W. L. Brown, Jr., Research Report 88-29, File 18967, Caterpillar Tractor Company, June 22, 1981.

4. "Transient Cycle Arrangement for Heavy-Duty Engine and Chassis Emission Testing," Chester J. France, EPA Report HDV 78-04, August 1978.

5. MVMA-Modified Heavy-Duty Gasoline Engine Transient Emission Test Cycle, Attachment, Letter to EPA Administrator, Motor Vehicle Manufacturers Association, February 15, 1982 (see EPA Public Docket No. A-81-11, IV-D-2 and IV-D-2a).

4. Issue: Environmental Impact

Summary of the Issue

The impact of this rulemaking on the nation's air quality was a topic of substantial comment. Many commenters were critical of the revised rule on the grounds that it would not lead to the maximum possible air quality improvements, while others criticized it as being more stringent than is necessary.

Summary of the Comments

Comments arguing that this rule fails to force the maximum achievable air quality benefits were received from the following individuals and organizations: Senator Gary Hart of Colorado; Frances J. Scherer of New York, a private citizen; the National League of Women Voters (LWV); the Manufacturers of Emission Controls Association (MECA), an industry trade group; the Natural Resources Defense Council (NRDC); the Regional Air Pollution Control Association (RAPCA) of Dayton, Ohio; and the Western New York Allergy and Ecology Association (WNYAEA). These state and local LWV affiliates also submitted comments: Michigan; Carson City, Nevada; New York City; and Doylestown, Pennsylvania.

Those maintaining that the revised rule is still unnecessarily stringent from the standpoint of achieving the desired improvements in air quality were all manufacturers. The comments of Ford Motor Company (Ford), General Motors Corporation (GM), International Harvester (IH), and Mack Truck (Mack) are summarized after those of the commenters listed above.

All of the commenters in the former group (opposing relaxation) maintained that these revisions to the light-duty truck (LDT) and heavy-duty engine (HDE) emission rules pose a threat to the public health and welfare. Citing figures from the December 1979 EPA Regulatory Analysis projecting average improvement of 7 percent in 1995 for carbon monoxide (CO), Senator Hart noted that for cities with very high CO levels such as Denver and Los Angeles, this difference could "...determine whether or when the ambient air quality standards will be achieved." The LWV, MECA, NRDC, and RAPCA all cited this figure, and the 2 percent average improvement for ozone in 1995 projected in the same document, to argue that air quality improvements of that magnitude are necessary if areas currently in nonattainment status for either pollutant are to be brought into compliance.

The NRDC, MECA, and LWV all noted that control of hydrocarbon (HC) and CO emissions from HDEs has previously been found to be cost effective, and that the control technology necessary to meet the statutory standards is available. Emissions from HDEs have not been reduced to nearly the extent that light-duty vehicle (LDV) emissions have, NRDC and LWV stated; thus, HDEs have not borne their proportionate share of mobile source emissions reductions and associated costs to date.

MECA listed some of the air quality problems foreseen by the Association of State and Territorial Air Pollution Administrators (ASTAPA) "...if auto and truck emission standards are relaxed." Citing To Breathe Clean Air, the 1981 final report of the National Commission on Air Quality (NCAQ), and EPA-supplied data, MECA noted that violations of the National Ambient Air Quality Standard (NAAQS) for ozone are projected to occur through at least 1995 and stated that "...it is generally agreed that if the ozone air quality standard is ever to be achieved all feasible and reasonable hydrocarbon controls will be needed."

MECA indicated that even if it were concluded, contrary to "clear and compelling evidence," that adequate control of HDE emissions of HC and CO could be achieved without the use of catalysts, catalyst technology should still be implemented. Catalysts offer "an attractive answer to [future] gasoline-truck NOx control," MECA stated, and rejection of catalysts for HC and CO control at this time will make it more difficult to implement such technology in the future.

RAPCA was critical of the lack of detailed air quality analysis data included in the Federal Register publication of this rulemaking, stating that the information provided "...is so sparse as to make it virtually impossible to determine the impact of the anticipated emission increases on the Dayton Region." Since the Dayton area is currently operating under a nonattainment State Implementation Plan (SIP) for ozone, RAPCA finds it difficult to accept EPA's "...conclusory assertion of no impact." RAPCA also called it unseemly for EPA to propose "a large increase in truck emissions" and assert that the impact on air quality will be small, while simultaneously "restricting access" to the detailed information (air quality modelings) necessary for independent evaluation of EPA's conclusions.

In addition to their concerns over the ozone and CO air quality impacts of this rule, LWV expressed reservations about anticipated increases in lead emissions from HDEs as compared to the original 1984 rulemaking. They contended that the relaxation of the HDE emission standards to non-catalyst levels will increase lead emissions both directly, through continued

HDE lead emissions which would have been eliminated under the originally promulgated standards, and indirectly, through extension of a legitimate source of demand for leaded gasoline at the retail level, thereby extending the opportunity for misfueling of catalyst-equipped LDVs and LDTs.

NRDC documented its opposition to this rule using many quotes and figures taken from EPA's December 1979 Regulatory Analysis. In addition, pertinent quotes were taken from House Report No. 95-294 (95th Congress, 1st Session, 1977), the NCAQ final report, other reports by the National Academy of Science, the Library of Congress, and the New York City Department of Air Resources, a study conducted by the Jet Propulsion Laboratory, and former Senator Edmund Muskie, floor manager for the 1977 Clean Air Act (the Act) amendments. All of these stressed the need for further control of HDE emissions.

Finally, NRDC also claimed that the air quality impacts calculated by EPA and included in the September 1981 Draft Regulatory Support Document are significantly understated when the deterioration factors (DFs) contained in EPA's January 15, 1982 response to questions from Senator Robert Stafford of Vermont on motor vehicle emission standards are used. NRDC claimed that EPA used different (and lower) DFs in the Regulatory Support Document. On this basis, NRDC urged "...that EPA reanalyze the air quality impacts, impacts on nonattainment status, and impacts on the number of exceedances using the more recent deterioration factors submitted to Congress."

The remaining comments concerning the air quality impacts of this rule are those of the manufacturers. All felt that the rule, even as revised, is unnecessarily stringent for attainment of the air quality benefits sought. Several different bases for this position were advanced.

Ford and Mack both questioned the need to control HC emissions from HDEs to the extent required in the rule, on the grounds that all areas exceeding the NAAQS for ozone are urban, while much of the HC from heavy-duty trucks (HDTs) is emitted in rural areas. Ford stated that approximately half of all HDT vehicle miles travelled (VMT) are in rural areas, and that the air quality impacts for ozone and CO projected by EPA are therefore approximately twice the magnitude of the actual impacts. Mack quoted the Department of Commerce 1977 Truck Inventory and Use Survey, which showed that only 22 percent of the VMT of Class VIII heavy-duty diesels (HDDs) are accumulated in urban areas. On this basis Mack, which manufactures only heavy-duty diesel engines (HDDEs) for Class VIII applications, stated that EPA must consider the fraction of all HDT VMT that are accumulated in urban areas when performing air quality analyses.

Mack also accused EPA of failing to use the findings of the August 1980 pollutant-specific study (PSS) for HC when setting the standards for HDDEs. Its argument can be summarized as follows: The 57 areas in violation of the NAAQS for ozone are all urban areas. According to the PSS, in 1999 HDDEs will be contributing only 4.7 percent of total HC emissions in those 57 areas. (Mack added that a report by Southwest Research Institute (SwRI) shows that this HDDE fraction of total HC will be only 3.6 percent in 1999.) The SwRI report also said that $377 million would be spent during the 1990's on control of HC from HDEs, in order to bring "only one or two AQCRs" into compliance. Since further control of HC from HDDEs is "obviously" not cost effective based on this information, Mack concluded, EPA did not use the findings of the PSS in setting the standards. In failing to do so, Mack claimed that EPA has "...overlooked a very important and significant issue."

IH recommended that EPA perform a complete reanalysis of all air quality and cost/benefit questions, taking into account two factors that they maintained were not considered. The first of these dealt with the multiplier that EPA used to convert 1979 certification HC emission rates to equivalent 1984 transient cycle HC emission rates for HDDEs. In the December 1979 Regulatory Analysis, EPA used a multiplying factor of 2.4 to make this conversion. IH states that their testing and that of other manufacturers indicates that the value of this multiplier should have been 1.3; therefore, EPA overestimated pre-1984 HDDE HC emissions by a factor of 1.8 (2.4/1.3).

According to IH, EPA also used "unrealistic estimates of the trend to diesels in the heavy-duty market" in the Regulatory Support Document. By underestimating the magnitude of the shift to diesels in the 1980s and overestimating the level of HC emissions from 1979-83 HDDEs, IH argued, EPA has based its ambient air quality arguments for the transient test and emission standards on faulty assumptions. IH maintains that the air quality benefits intended to result from this rule will "by and large" be accomplished through continued diesel penetration of the HDE market in the 1980s.

In arguing for their proposed HDE emission standards, Ford also made reference to the latest projections for diesel penetration of the heavy-duty market in the 1980s. Ford then described the results of their own air quality analyses in which the impact of the standards being set at 3.3 HC/42 CO, rather than 2.5 HC/35 CO as specified in the proposal, is seen to be quite small. These impacts are given as "considerably less than one percent" foregone improvement for ozone as of the year 2000 and "one percent or less" foregone improvement for CO as of 1995.

General Motors criticized the estimates of HDE fuel economy (FE) that EPA used, arguing that they may have been too low by as much as a factor of two and, that as a result, HDE emissions and their contribution to overall air quality may be overstated by a factor of two. General Motors noted that EPA used FE estimates of 5.0 miles per gallon (mpg) for heavy-duty gasoline engines (HDGEs) and 5.8 mpg for HDDEs, derived from the EPA transient HDE test cycles, which in turn were based on CAPE-21 survey data. They argued that the survey did not include any heavy-duty gasoline vehicles (HDGVs) from Class IIB (8,501-10,000 lbs. gross vehicle weight (GVW)), which are the largest subset of all HDGVs and have average fuel economy of considerably more than 5.0 mpg. In addition, EPA assumed that these FE values would be constant throughout the projection period; actually these values are expected to rise significantly during the 1980s, GM said, partly due to increasing diesel penetration of the lower-GVW heavy-duty classes.

Most of the comments made by GM sought to minimize the significance of this rule to national air quality. GM argued, for example, that "...clearly, any HC standard more stringent than the 1979-83 HDE standard would be adequate to avoid significant effect on urban air quality." On the basis of the "negligible" and "insignificant" air quality improvements projected, GM maintained: 1) that a Selective Enforcement Audit program for HDEs cannot be justified; 2) that extended useful-life requirements are unnecessary; and 3) that the 1984 LDT requirements will have no significant impact on air quality violations. GM concluded that HDE standards of 3.5 HC/70 CO will "allow early attainment of the NAAQS in even the worst areas of the country," while having minimal cost impact, eliminating the need for overtemperature protection controls, and not imposing any fuel penalty.

Analysis of the Comments

The subissues raised by the commenters are discussed in this section in roughly the same order as they were presented in the summary section.

At the outset, it is important to keep in mind the statutory authority and Congressional guidelines for this rulemaking. The emission standards are being revised principally under the authority of Sections 202(a)(3)(B) and (C). Although EPA has evaluated the air quality effects of this rulemaking, the revised standards are based on findings concerning cost, technology and leadtime, as explained in the preamble and elsewhere in this document. Congress has specified that revised standards provide for "the maximum degree of emission reduction which can be achieved by means reasonably expected to be available" for the duration of the revised standards, set against an ultimate Congressional goal of 90 percent emission reductions, also established in these rules for lighter HDEs.

Thus, the comments on both sides of the issue of the appropriate degree of air quality protection are somewhat misplaced. Although the air quality effects of these rules are important, air quality considerations are not the driving force behind the amendments.*

In the December 1979 Regulatory Analysis, EPA projected average air quality improvements in 1995 of 7 percent (CO) and 2 percent (ozone). Commenters noted that improvements of this magnitude are very important for areas that exceed or just meet the NAAQS for either pollutant, and could be the deciding factor in whether and when cities with very high CO levels reach attainment of the standard. EPA concurs with the importance of HDE emission reductions to such areas, and notes that air quality improvements of 5 percent (CO) and 1 percent (ozone) are still projected in 2000 as a result of this rule. EPA considers the HDE emission standards being promulgated in this action to be the most stringent reasonably available at this time, taking into consideration such issues as leadtime, cost effectiveness, technological feasibility, and fuel economy effects. These factors are dealt with in more detail in other sections of this document.

Commenters indicated that further emission controls for HDEs have been shown to be cost effective and technologically feasible, and that the statutory standards mandated in the 1977 amendments to the Act can be achieved. It was stated that the 1979-83 HDE emission standards are too lenient; the sharp

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* As described elsewhere, air quality effects do bear on related portions of these rules. For example, EPA selected a modified full-life useful-life requirement over a half-life approach based in part on the Agency's determination that the former approach helps assure that the full air quality benefits of these rules will be realized. So, too, EPA in allowing the use of manufacturers' test cycles has adjusted standards to assure that the air quality benefits of the previously promulgated standards will not be compromised.

contrast in the degrees of emission control required of light-duty vehicles (LDVs) and LDTs, and of HDEs in the same time period, was cited. EPA agrees that the current discrepancy in HDE and LDV/LDT emission control requirements is inequitable in the long run, and that significant reductions in HDE emissions may be achieved at reasonable cost. This rule substantially reduces the inequality in the stringency of light-duty and heavy-duty emission control requirements, and results in lifetime per-vehicle emission reductions for HDGEs of 0.25 tons HC and 16.42 tons CO (representing reductions of 39.5 and 73.6 percent, respectively, from model years 1979-83 lifetime emission levels).

According to MECA the use of catalytic converters on HDGEs should be required, even if the HC and CO emission standards are set at levels that would not require the use of catalysts, because substantial fuel economy gains could be realized and catalysts provide an attractive method for future NOx control from HDGEs. The LWV said that requiring catalysts on HDGEs would decrease future misfueling, while MECA said it would allow more stringent future NOx control and increase fuel economy. These points are acknowledged, but it should be noted that EPA does not specify what emission control technology should be used to meet any emission standards. In addition, the revisions in the HC and CO standards for HDGEs contained in this rulemaking for 1985-86 are only temporary. Catalysts will be used on the majority of HDGEs beginning in 1987 to meet the statutory standards.

The concerns of ASTAPA as outlined in the MECA comments are understandable; especially if, as stated in the comments, both auto and truck emission standards were being relaxed. This rule has no bearing on LDV emission standards or test procedures; and while the HDE standards are being temporarily revised, the standards contained in this rule are still considerably more stringent than those in effect for model years 1979-83. The air quality analyses, which are discussed in detail in Chapter 2 of the Regulatory Support Document, show that the "worst-case" fears of ASTAPA are unfounded.

After receiving the RAPCA comments, which criticized the lack of detailed air quality data included in the Federal Register Notice of this rulemaking, EPA immediately provided them with copies of all air quality analyses. Since the period for public comment on this rule was subsequently extended for 21 days, RAPCA had the opportunity to comment further after receipt of those analyses.

The National Resources Defense Council's claim that EPA used two different sets of deterioration factors, one shown in the September 1981 Draft Regulatory Support Document and the other submitted in response to Senator Stafford's questions, is erroneous. NRDC apparently took deterioration factor (DF) and deterioration rate (DR) to be synonymous. They are not. Senator Stafford asked for HDG vehicle DRs, while the calculation of lifetime per-vehicle emissions in the Draft Regulatory Support Document used DFs.

Deterioration rates are based on testing of vehicles in the field, while DFs are derived from manufacturers' certification data. Both quantities attempt to describe the deterioration in the emissions of a vehicle or engine. However, the DR accounts for many in-use causes of deterioration not accounted for in the DF, including causes that might not be directly within a manufacturer's control. In-use deterioration (i.e., the DR) includes the effects of climatic extremes, inadequate maintenance, and tampering and abuse, as well as the normal wear and tear which the DF is supposed to represent. Thus, as the comment by NRDC reflected, the DR and the DF can be and usually are very different numbers.

The Agency's air quality model uses DRs, not DFs, to model the deterioration of emission levels with increasing mileage. The DFs are used in the calculation of the zero-mile emission levels (ZMs), and thus are only used indirectly by the model. The air quality analyses used in the September 1981 Draft Regulatory Support Document, and in the final Regulatory Support Document which accompanies this Final Rule, used the DRs submitted to Senator Stafford. The model's outputs (including the number of urban areas in violation, the number of exceedances, the average percent reduction, and the inventory in tons of pollutant) therefore result from the use of DRs, not DFs. The only instance where DFs were used was in the calculation of the per-vehicle lifetime emissions for the Draft Regulatory Support Document. DRs can also be used to calculate the per-vehicle lifetime emissions, and are more accurate if absolute numbers are desired. However, the calculation in the Draft Regulatory Support Document used DFs because the focus was on relative numbers, that is, on the differences between the scenarios rather than the absolute number of tons under each scenario. These relative numbers using either a DR or a DF calculation are about the same. The final Regulatory Support Document uses the DR calculation, since the focus is on the absolute, as well as the relative numbers.

The remainder of this section is devoted to discussion of the comments submitted by the manufacturers. Several of these comments raised issues that, while valid points of concern, are beyond the immediate issue (the air quality impact of this rulemaking) and are not subject to quick or simple resolution. Neither are they considered by EPA to be of sufficient magnitude as to affect the rulemaking decision process. Such issues include the urban/rural VMT split cited by Mack and Ford, and the criticism by GM of the heavy-duty fuel economy estimates and the representativeness of the CAPE-21 data base. EPA allows that improvements in the accuracy of the air quality projections are possible. However, dealing thoroughly and appropriately with questions such as those mentioned above is not a trivial exercise. EPA is concerned with improving the accuracy of the air quality model and the assumptions that go into it, and efforts to do so will continue in the future. However, at this time EPA notes that there is no reason to consider rural HC emissions to be unimportant. Ozone is a regional pollutant, and in the time that HC emissions are reacting to form ozone, they could travel a considerable distance from their original emission points.

Mack cited the August 1980 pollutant-specific HC study to argue that further HDE HC emission controls are not cost effective. While cost effectiveness may to some extent be relative, EPA feels that the cost effectiveness of further HDE emission control has been demonstrated to be good, as described in a recent EPA staff paper.[1] The staff paper analysis considers EPA's best estimates of both costs of this action and its associated air quality benefits in arriving at that conclusion. The point raised by Mack about the relatively small contribution from HDDEs could be equally applied to many other HC emission source categories and lead to the erroneous conclusion that none of these sources need be controlled according to Mack's logic. Since HC emissions include a large number of relatively small sources, it is important if progress is to be made to control HC emissions wherever that can be done in a cost-effective manner.

EPA rejects IH's contention that the multiplying factor used to convert 1979 certification HDDE HC emission data to equivalent 1984 transient test emission data should have been 1.3, and not 2.4 as used by EPA. The value of 2.4 used by EPA was based on the results of tests of HDDEs manufactured by Caterpillar, Cummins, and Detroit Diesel Allison (GM). While EPA acknowledges that these tests were conducted several years ago and that considerable additional testing has since been conducted, it is also noted that IH did not submit any new data to support their claim. The value of 2.4 is intended to be representative of the heavy-duty industry as a whole; thus it is entirely possible that the 1.3 value may be more accurate for IH engines alone, for example. Basically, this comment is unrelated to the air quality impact of this rule.

In response to claims by the manufacturers that EPA used unrealistically low projections of diesel penetration of the heavy-duty market in the 1980's, thereby overestimating the contribution of the heavy-duty fleet to overall air quality, EPA notes several things. First, a major premise of this argument is invalid. Stating that HDDEs will always have lower lifetime HC emissions than HDGEs, given the same standard and useful life for both engine types, is simply not true. The zero-mile emission rate is higher for HDDEs than for HDGEs under the same standard. Our calculations show that, under the same standard, HDDEs will emit more HC than will HDGEs over the lifetime of the engine. It is only the fact that the HDDE HC standard will be lower than the HDGE HC standard for 1985-87 that makes HDDEs "cleaner." Second, EPA acknowledges that the nature of the heavy-duty market has changed somewhat since the original Regulatory Analysis was published. However, as was noted by IH in their discussion of this point, there are factors (such as sudden changes in fuel costs) that can cause the rate of diesel penetration of the heavy-duty market to change dramatically in a short time; thus, any projections, whether by EPA or the manufacturers, are at best educated guesses and subject to quickly being overtaken by events.

Finally, in terms of air quality the crucial estimate is the relative change in HDDE and HDGE VMT, not the changes in vehicle registrations or HDE market shares. EPA assumed that HDDE VMT would increase by 5 percent annually, while HDGE VMT would decrease by 2 percent annually during the same time period. These estimates still appear reasonable.

Ford's air quality projections, showing almost no decrease in air quality if the standards of 3.3 HC/42 CO advocated by Ford are implemented rather than the 2.5 HC/35 CO specified in this rule, appear to be valid. EPA simply notes that small, incremental relaxations in emission standards will, by definition, result in relatively small air quality impacts. Extending Ford's line of reasoning, any and all emission standards could be discarded incrementally, since each incremental air quality impact would be minimal. Given both the current and projected future need for improvements in ozone ambient air quality, EPA must reject Ford's approach. All reasonably attainable HC control is important in terms of air quality. The proposal by GM that interim standards be set at 3.5 HC/70 CO must also be dismissed on the same grounds, since this proposal represents virtually no reduction from the 1979-83 emission levels. Finally, EPA also notes that §202(a)(3)(B) of the Act requires that when interim emission standards less stringent than those mandated are implemented, those interim standards represent "...the maximum degree of emission reduction which can be achieved by means reasonably expected to be available for production." Both the Ford and GM proposals are inconsistent with this requirement of the Act.

Conclusions

Although EPA recognizes the concerns of those opposed to any revisions to the HDE gaseous emission standards, and also recognizes that some of the points raised by the manufacturers merit further study, EPA concludes that the Agency is acting within its legislative authority in promulgating both the interim non-catalyst emission standards and the long-term reductions in these rules. Further changes to this rule are not justified on the basis of these comments.

References

1. "Issue Analysis - Final Heavy-Duty Engine HC and CO Standards," Staff Paper, U.S. EPA, OMS, OANR, ECTD, SDSB, March 1983.

B. Secondary Issues

1. Issue: Deterioration Factors

Summary of the Issue

In the original FRM, EPA finalized provisions for the application of multiplicative deterioration factors to HDE exhaust emissions. Commenters opposed this change from the previously used additive deterioration factors. Comments were also received indicating that negative deterioration factors should be accepted by EPA. One comment concerned the methods used to determine deterioration factors.

Summary of the Comments

Most of the comments criticized the application of multiplicative deterioration factors to HDEs. These comments argued that no justification exists for the use of multiplicative deterioration factors with non-catalyst emission control systems. It was also noted that, in the opinion of the commenters, multiplicative deterioration factors effectively increase the stringency of the applicable emission standards, particularly those at low numerical values, thereby increasing the control system development costs to the manufacturers.

Comments requesting that EPA recognize the validity of negative deterioration factors were received from EMA, with supporting data on HDEs being provided by several manufacturers. These data show that some HDE exhaust emissions, particularly NOx, may actually decrease over the useful life of the engine. One engine manufacturer also submitted data which it claimed demonstrated that properly maintained HDEs have no significant deterioration in emissions during useful life, and that emissions have been observed to decrease in some cases.

One comment was made concerning the method used to determine deterioration factors. The commenter maintained that deterioration factors should be determined through 1,000-hour durability runs per §86.082-28(c)(4), and not by fleet tests with uncontrolled parameters.

Each of the comments concerning the application of multiplicative deterioration factors to HDEs cited the lack of justification for extending the use of multiplicative deterioration factors to vehicles and engines using non-catalyst emission control systems. A few also noted that the use of multiplicative deterioration factors cannot be justified now on the basis of possible regulations implementing trap-oxidizer technology for HDDEs in the future.

Analysis of the Comments

EPA's analysis in support of the original FRM[1] did not provide conclusive evidence that one type of deterioration factor was more appropriate than the other for engines without aftertreatment devices. That analysis did conclude that multiplicative deterioration factors are more representative of actual emission deterioration when aftertreatment technology is used, however, since such technology reduces emissions on a proportional basis. Therefore the use of multiplicative deterioration factors should still be required for vehicles or engines utilizing aftertreatment technology.

The possibility that durability testing of a vehicle or engine may result in an additive deterioration factor less than zero, or a multiplicative deterioration factor less than one, is recognized. However, at least for HC and CO, EPA views such results as anomalous and clearly not indicative of actual in-use deterioration. At best, a well-maintained engine could be expected to exhibit stable emission levels; there is no mechanical reason for in-use HC or CO emissions to decrease with accumulated time or mileage. In addition, accepting such deterioration factors would allow relaxation of low-mileage target levels to values above those otherwise required for compliance at low mileages. This would be incompatible with the purpose behind the use of deterioration factors in certification, which is to estimate the highest emission level a vehicle is expected to exhibit over its life so that compliance is assured on that basis. If emissions were expected to decline with mileage or time, then the level of concern for certification purposes would be the unadjusted new-vehicle level. Thus, EPA feels that the current rule, under which an additive deterioration factor of less than zero is considered to be zero and a multiplicative deterioration factor of less than one is considered to be one, is justified.

The comment concerning methods of determining deterioration factors can be addressed quite briefly. The determination of deterioration factors is entirely the responsibility of the manufacturer; within certain constraints, so are the methods and procedures used in the determination. Section 86.082-28(c)(4) does not specify that 1,000-hr durability runs or fleet tests by used to determine deterioration factors, but refers only to "...deterioration factors, determined from tests of engines, subsystems, or components conducted by the manufacturer."

Conclusions

While studies[1] have been inconclusive regarding the appropriateness of multiplicative deterioration factors for non-aftertreatment vehicles and engines, they are clearly more accurate in describing deterioration in the performance of proportional-reduction devices. Thus, EPA has decided to delay the required use of multiplicative deterioration factors for HDEs until such time as more stringent emission standards requiring the use of catalysts (for HDGEs) or particulate traps (for HDDEs) are established and implemented. The first use of multiplicative deterioration factors will then be for lighter HDGEs certifying to the statutory standards in 1987. For reasons cited in the analysis, EPA also has decided that additive deterioration factors of less than zero and multiplicative deterioration factors of less than one will continue to be taken as equal to zero and one, respectively.

References

1. "Summary and Analysis of Comments to the NPRM: 1983 and Later Model Year Heavy-Duty Engines, Proposed Gaseous Emission Regulations," U.S. EPA, OANR, OMS, ECTD, SDSB, December 1979.

2. Issue: Idle CO Test and Standards

Summary of the Issue

In the original FRM, EPA finalized a separate standard and test procedure for idle CO emissions from gasoline-powered LDTs and HDEs. The commenters on this issue were unanimous in their opposition to these requirements. Much of the criticism stressed the allegedly redundant nature of the test and the planned use of the test by EPA to detect failed catalysts and set lower I/M cutpoints. One manufacturer claimed that the idle test requirements will force it to include additional hardware on its LDTs. Several procedural and technical questions were also raised.

Summary of the Comments

The manufacturers commenting on this issue all criticized the idle CO test as redundant, unnecessary, and unjustified. Several claimed that the 26.8 percent of the transient certification test spent idling guarantees that idle CO emissions must be closely controlled in order to pass the entire test. The comments indicated that the added cost and complexity of certification including the idle test would thus be an unnecessary burden on the manufacturers.

EPA was also criticized for planning to use data from idle CO tests in the detection of failed catalysts and the establishment of lower I/M cutpoints. One comment specifically cautioned EPA to "avoid the belief that idle CO measurements would be a viable method of in-service compliance checking."

Several commenters indicated that EPA cannot promulgate the idle CO test without demonstrating that a reasonable correlation exists between the idle test and the other required CO measurements (transient cycle and performance-warranty short test). According to the commenters, this correlation is required under Sections 206 and 207(b) of the Clean Air Act and has not been demonstrated.

The numerical level of the standard was criticized in several of the comments. One manufacturer criticized the standard as infeasible and said that it should be revised upward to reflect non-catalyst technology, while another indicated that the dry volumetric measurements used make the same numerical standard more stringent for smaller-engine vehicles. Volkswagen questioned the authority of EPA under Section 202(a)(1) of the Clean Air Act to implement the same numerical standard across the entire LDT class, noting that it would be forced to install "new systems" on its LDTs less than 6,000 lb. GVWR simply because of the idle CO standard.

Volkswagen submitted data on idle emission characteristics relative to FTP results from two of its light-duty pick-up trucks. While these vehicles met the current FTP standards for HC, CO, and NOx emissions, the volumetric tailpipe idle CO measurements were between 1.3 and 1.4 percent. VW claimed that these data show that it would be forced to install new systems on these trucks solely because of the idle requirements. VW also noted that these vehicles would otherwise be able to meet the emission standards promulgated for 1984 and later LDTs with minor calibration changes.

In a follow-up conversation between EPA and VW staff, the possibility of adjusting the idle A/F mixture to a leaner setting in order to reduce idle CO was discussed. VW expressed concern that leaning the idle A/F ratio, combined with the possibility of in-use drift of this setting, could result in engine stalling problems. Should leaning of the idle A/F mix either fail to bring idle CO under the standard, or result in unacceptable driveability problems, VW stated it would be forced either to install a "new system" (air pump) in its LDTs or to go to a closed-loop system. VW indicated that it would prefer the closed-loop solution.

Finally, several minor issues were addressed in the comments: the inclusion of the idle CO test in SEA testing, the applicability of DFs to idle emission data, and the scarcity of data on idle CO deterioration throughout the useful life of a vehicle or engine.

Analysis of the Comments

Each of the comments criticizing the HDGE idle CO standard and test as redundant pointed to the 26.8 percent of total time spent idling in the transient test cycle. It was argued that since the transient cycle is deemed representative of in-use operation, idle mode emissions are adequately represented. (One manufacturer made the same argument for LDTs, noting that 18 percent of the time in the FTP cycle is spent idling.) Strict control of idle emissions was claimed to be necessary in order to certify under the transient cycle test procedure.

EPA rejects the manufacturers' contention that strict control of idle emissions is prerequisite for certification under the transient cycle test procedure. This contention is based on the large portion of the time in the transient cycle (26.8 percent) that is spent at idle. In calculating CO emissions for certification, the total mass CO emissions generated during the test are divided by the total work performed by the engine during the test, yielding a result in g/BHP-hr that is measured against the applicable standard.

Since the volumetric exhaust flow is much lower at idle than at higher engine speeds, the mass contribution of CO during the idle portions of the transient cycle is not proportional to the time spent at idle. As a result, the 26.8 percent of the cycle time spent idling contributes much less than 26.8 percent of the total mass CO emissions. Thus, the statement that strict idle mode emission control is required in order to be certified using the transient cycle test procedure is not true.

In fact, one manufacturer's comments supported the EPA position on this issue. Data submitted on two HDGEs (4.9L and 6.1L) showed that of the total CO emissions during the transient test, only 14 percent and 3 percent respectively were contributed by the idle mode segments of the transient cycle. The manufacturer states that "...the idle test in no way reflects the ability of an engine to comply with the transient test." EPA notes that the converse of this statement, that the transient test does not reflect the ability of an engine to comply with the idle CO test, logically follows; this undercuts the assertion that the idle test is redundant.

The cost-per-vehicle of the idle test requirements is minimal. Since compliance with the standard is virtually automatic with the use of catalysts, there are no associated development or hardware costs. Even in the case of non-catalyst systems, only small development and calibration costs are likely. The only other cost is that of conducting the idle tests during certification and SEA, which is very small on a per-vehicle or per-engine basis. With the benefits discussed herein, EPA cannot agree that these requirements constitute an unnecessary or unreasonable burden on the manufacturers.

The detection of failed in-use catalytic emission control systems will have a positive impact on air quality. These benefits will be achieved through reduction of the number of gross-emitting in-use vehicles. While several commenters stated that the idle standard cannot be used as a practical I/M cutpoint, no data were provided supporting this assertion. The only substantive comment received in this respect noted that idle CO levels are largely a function of previous operating conditions, including pre-test idle time, evaporative content, over-temperature conditions, and fuel volatility. EPA remains convinced that the idle CO requirements are appropriate for catalyst-equipped vehicles and engines, and will be a useful tool in the detection of failed catalysts. Since this is the most important application of the idle test requirements, however, EPA agrees that these requirements should be deferred for HDGEs until more stringent HC/CO emission standards requiring the use of catalytic control technology take effect in 1987.

MVMA and several of the manufacturers challenged the idle standard and test procedure on the basis that EPA has not yet established a "reasonable correlation" between the idle test and the other standards and procedures applicable to the control of CO emissions, as required by Sections 206 and 207(b) of the amended Clean Air Act. The issue is premature. EPA has not proposed to use the idle CO test as a "short test" for enforcing the performance warranty under Section 207(b). If EPA takes that step, the issue of "reasonable correlation" will then be ripe.

Comments regarding the numerical level of this standard contained no information to justify a relaxation. One manufacturer suggested that the proposed standard be revised upward to reflect non-catalyst technology. Since the EPA recommendation (above) is to limit the applicability of the idle CO test to vehicles and engines utilizing aftertreatment technology, and since all HDGEs will be capable of meeting the revised HC/CO emission standards without utilizing such technology, this comment need not be addressed further.

The question of the appropriateness of the dry volumetric method of measurement used in the idle test and whether the standard is thereby effectively made more stringent for vehicles using smaller engines was raised. The method of measurement to be used in the idle test procedure was taken into account in the setting of the standard, and so the stringency of the standard is not greater than was intended. Smaller engines must have a slightly richer A/F mixture at idle to avoid problems with stalling, which implies that the idle CO emissions of a smaller engine could be somewhat greater than those of similar but larger engines. However, the use of catalysts should make compliance with the idle standard easily attainable by engines of all sizes that are affected by these requirements. In addition, EPA notes that data submitted by one manufacturer, on idle CO emissions from 15 LDTs with engine displacements ranging from 1.9L to 5.7L, showed that the average idle CO emissions of well-maintained vehicles with properly functioning catalytic systems were markedly below the standard. These data do not support the contention by the manufacturers that vehicles using relatively smaller engines will have an effectively more stringent idle CO standard to meet.

Several commenters discussed the applicability of the idle CO standard and test procedure to LDTs, although this issue was not officially open for comment. The issues and analyses surrounding LDTs are the same as those discussed above for HDEs. In particular, EPA notes these relevant facts: The inclusion of the idle test requirements in the certification procedure serves a valid purpose. Section 206(a)(1) of the Act allows such test requirements to be implemented. The earlier discussion, indicating that the mass CO contribution of the idle portions of the transient test is proportionally much lower than the percent of cycle time spent at idle, is equally applicable to the idle portions of the FTP.

In reference to VW's assertion that these regulations will require the use of additional emission control hardware on its LDTs, EPA notes that data submitted by other manufacturers showed idle CO levels for LDTs to be well within the standard. The idle CO standard went through an extensive proposal and comment period as part of the original LDT rulemaking, and the record indicates that neither VW nor any other LDT manufacturer raised any issue over the feasibility of the standard. Since that time, VW has certainly had an adequate period of leadtime to meet the new requirements. VW should investigate the possibility of meeting the idle standard through adjustment of idle A/F settings. If this approach results in driveability problems unacceptable to VW or fails to bring idle CO levels under the standard, then one of the other two options (closed-loop system or air pumps) should be exercised.

Turning now to the lesser issues raised, the first concerns the use of the idle test in future SEAs. The idle test procedure, as an integral part of the certification procedure for vehicles and engines utilizing aftertreatment technology, will be included in SEA testing.

The use of DFs with idle emission data was questioned by one manufacturer, who noted the lack of data on idle CO deterioration during useful life and the fact that negative DFs are not allowed. In response, EPA notes that the application of DFs is required for <u>all</u> emission standards, and therefore will be required for this standard. Although negative DFs are not allowed, manufacturers having data showing that no deterioration occurs for a given regulated emission during the useful life, can use a multiplicative DF of 1.0 or an additive DF of zero, thereby demonstrating useful-life compliance with that standard at the time of certification.

The lack of idle CO deterioration data for non-catalyst vehicles/engines, which was addressed by another manufacturer, is not an issue. As noted earlier in this section, vehicles and engines not utilizing aftertreatment control technology will not be subject to the idle CO standard and test requirements.

Conclusions

The primary benefit of the idle CO standard and associated test procedure will be in the detection of failed in-use catalytic emission control systems. With this in mind, EPA has decided to delete the idle test requirement for all vehicles and engines that do not utilize aftertreatment control technology, but to retain it for catalyst-equipped vehicles and engines. Hence for HDGEs, the idle test requirements will be delayed until more stringent HC/CO standards requiring the use of catalysts take effect. To make the standard and the test more practically useful, in terms of the degree of accuracy needed for both certification and in-use testing, the original standard of 0.47 percent will be rounded to 0.50 percent.

The comments submitted on this issue contained no information justifying additional changes in these requirements.

3. Issue: Fuel Economy

Summary of the Issue

This analysis addresses the fuel economy impact of emission standards for heavy-duty gasoline engines (HDGEs) for 1985 and later model years. Two separate issues are included: 1) the fuel economy effect of 1985 HC and CO emission standards that are achievable without catalysts, and 2) the fuel economy effect of catalyst-based HC and CO standards for 1987 and later model years.

Summary of the Comments

The consensus of the gasoline engine industry is that a substantial fuel economy penalty would result from the use of stringent non-catalyst standards, such as those originally proposed.

General Motors (GM) asserted in July 1981 that with full life and 40 percent AQL requirements, the fuel economy penalty will be around 2 percent for gasoline engines meeting standards of 3.7 g/BHP-hr HC and 45 g/BHP-hr CO, when compared to the 1979 baseline mpg. Its reasoning for the penalty was that the larger air pumps required to meet the standards will require more energy than that gained by having a leaner full power calibration.[1]

On March 16, 1983, EPA released for public comment a staff paper[2] which, among other things, discussed the expected fuel economy impact of the non-catalyst standards. For standards of 2.5 g/BHP-hr HC and 35 g/BHP-hr CO, EPA expected HDGEs to experience as much as a 10 percent improvement in fuel economy relative to 1979 engines. This estimate was based upon a review of data submitted by Ford in April 1982.

In its most recent comments,[3] GM criticized EPA for basing its estimate of a 10 percent fuel economy benefit on only two prototype Ford engines. GM presented confidential data to show that wide open throttle (WOT) power and fuel economy losses would occur on engines calibrated to meet standards of 1.3/35. (GM's WOT calibration was leaner than stoichiometry, and required substantial timing retard to preclude knock.) General Motors did not comment on the fuel economy impact of catalyst standards, nor has it commented on the fuel economy impact of non-catalyst standards of 2.5/35.

Ford's most recent comments of May 1983 also disputed the conclusions of EPA's staff paper. Based upon the current position of its product line, as submitted in its "best effort" data of May 1983, Ford claimed that those emission levels result in no significant change in power, fuel economy, or durability relative to 1979 requirements.[4]

Ford did not comment on the fuel economy impact of catalyst standards.

Analysis of the Comments

Non-Catalyst HDGEs

This section will review available fuel economy data, identify the likely emission control techniques to be used, and discuss the fuel economy effects as these techniques are applied to allow compliance with emission standards of 2.5 g/BHP-hr HC and 40 g/BHP-hr CO.

The data that are available for non-catalyst HDGEs are presented in Tables 3-1 and 3-2. Table 3-1 addresses GM's concern that only Ford data were used to assess the fuel economy impact of the standards. The GM data in Table 3-1[5] show that decreases in fuel consumption for their development engines range from approximately zero to 19 percent. None of the prototype engines had increased fuel consumption relative to their 1979 counterparts. The engine with the lowest emissions in both HC and CO had both the lowest fuel consumption, and the largest decrease in fuel consumption (19 percent) relative to 1979.

Examination of Ford's 1984 prototype engine data in Table 3-2[6] also shows that fuel consumption has decreased relative to 1979 HDGEs. (More recent data submitted by Ford[4] did not include BSFC.) Fuel consumption decreased by more than 7 percent when the average of all the April 1982 prototype tests are compared to all of the corresponding 1979 baseline engine tests. (Ford's concern that lab-to-lab correlation problems could lead to EPA drawing erroneous conclusions from available data is unfounded. Tentative results from the EPA/MVMA correlation project show superb agreement between laboratories for CO_2 emissions, the emission with the most direct bearing on fuel consumption calculations, and between BSFC results themselves.)

Aside from the actual data, there are theoretical reasons why fuel economy should improve as technology is applied to engines to meet non-catalyst standards of 2.5 HC and 40 CO. These theoretical reasons are based upon the combined fuel economy effects of the technologies which will likely be

Table 3-1

GM Development Data from August 1982[5]***

Engine	BSFC* 1979 Baseline	BSFC* Prototype	% Decrease in Fuel Consumption	Prototype Emissions** HC	Prototype Emissions** CO
292-L6	.655	.640	-2.29	2.41	21.82
	.655	.639	-2.44	2.17	24.93
350-2V8	.717	.604	-15.76	1.57	28.20
350-4V8	.727	.656	-9.77	2.08	29.02
	.727	.649	-10.73	1.99	27.22
366-V8	.719	.582	-19.05	.75	17.88
454-V8	.668	.666	-.30	1.01	22.18

Average (by engine family): -9.6 percent

* lbs/BHP-hr, EPA cycle based.

** g/BHP-hr, EPA cycle based.

*** GM stated in August 1982 that these data "are representative of HDGE emission control systems and calibrations which are currently believed to be at least plausible for production... [although]...[n]one of these arrangements have been durability tested..."[5]

Table 3-2

Ford Development Data from April 1982[6]

Engine Family	BSFC[1] 1979 Baseline	BSFC[1] Prototype	% Decrease in Fuel Consumption	Prototype Emissions[2] HC	Prototype Emissions[2] CO
4.9L	.696	.560	-19.54	1.66	23.2
6.1L	.681	.654	-3.96	2.33	28.8
7.5L	.633	.633	0.00	2.21	24.3

Average (by engine family): -7.8 percent

[1] lbs/BHP-hr, EPA cycle based.
[2] g/BHP-hr, EPA cycle based.

applied to comply with the non-catalyst emission standards: primarily leaner A/F ratios, retarded spark timing, and increased air injection.

A/F ratios for current technology (1979 requirements) HDGEs are generally quite rich, and it is expected that the new emission standards will require leaner carburetor calibrations. For example, GM stated that it has leaned out its A/F ratios on its 1985 prototypes at wide-open throttle, but that its calibrations are still on the rich side of stoichiometric. As a case in point, Table 3-3 shows the relationship between the A/F ratio, fuel consumption, and power for a Chevrolet 350-CID V-8 HDGE operating at wide-open throttle (WOT). As the A/F ratio was changed from 12:1 to 14.6:1, the fuel consumption dropped by 14 percent while the power declined by 6 percent.[7] The HDGE engine data presented in Table 3-3 represent performance only at WOT, and EPA concedes that WOT constitutes a small percentage of total cycle operating time. Logic suggests, however, that leaning A/F ratios to reduce HC and CO emissions over all combinations of operating modes on the transient test will also significantly improve HDGE fuel economy. Generally, leaner A/F mixtures decrease fuel consumption (BSFC) and therefore improve fuel economy (mpg).

Retarding spark timing also reduces HC emissions by raising post-combustion cylinder gas and exhaust gas temperatures, thus promoting oxidation of the HC emissions. This technique was widely used in pre-catalyst light-duty vehicles to control HC. However, retarding spark timing typically causes an increase in fuel consumption. For example, Ford data showed that by retarding initial spark timing by 4° (from 12° to 8° BTDC) on a 4.9L development engine, there was a 15 percent decrease in HC emissions, but a 5 percent increase in fuel consumption.[6,8] A similar analysis of a GM 350-V8 engine in a light-duty vehicle showed that retarding timing 20° from MBT resulted in a 10 percent fuel consumption increase at a 14:1 A/F ratio.[9] However, because of the relaxation of the non-catalyst HC standard from 1.3 to 2.5 g/BHP-hr, very little timing retard should be necessary to allow compliance, as suggested by the actual fuel economy data presented in Tables 3-1 and 3-2.

Increased air injection will also be used to reduce HC and CO emissions. For example, for its development engines, Ford replaced the standard two 19 in^3 pumps with two 23 in^3 pumps and added multiple injection points. These pumps had a 37 percent higher flow capacity.[6] There is, however, a practical limit to the amount of air injection; too much air can actually quench the oxidation reactions and preclude further emission reductions. (Ford experimented with a 50

Table 3-3

Chevrolet 350-CID V-8 Engine Data[8]

Air/Fuel Ratio	Fuel Consumption[1]	% Change in Fuel Consumption[2]	% Change in Power[2]
12.0:1	.575	--	--
12.8:1	.542	-5.7	-2.1
13.2:1	.525	-8.7	-2.9
13.8:1	.493	-14.3	-3.5
14.6:1	.493	-14.3	-5.9
15.0:1	.493	-14.3	-9.4

[1] lbs/HP-hr.
[2] Relative to 12:1 A/F ratio.

in^3 air pump, and observed no significant incremental emission reductions.) As with retarded spark timing, increased air injection reduces fuel economy. (Air pumps require energy to be driven.) EPA's own test data[10] indicate that there may be a 2.5 to 4 percent increase in fuel consumption if air injection rates are increased to the extent necessary for catalysts. (EPA expects the air injection rates for 1985 non-catalyst and 1987 catalyst engines to be similar.).

Other emission control techniques EPA expects to be used in 1985 should affect overall fuel economy very little. These techniques include early fuel evaporation systems, heated air intake, temperature-actuated timing retard, and automatic chokes. Early fuel evaporation systems use exhaust gases to heat the A/F mixture, resulting in reduced emissions and shorter warm-up periods. Shorter warm-up periods would promote better efficiency and therefore better fuel economy. Heated air intake also reduces engine warm-up time and allows leaner carburetor calibrations, thus better fuel economy. Cold temperature-actuated timing retard reduces cold start emissions at the expense of a slight increase in fuel consumption. These technologies are not anticipated to have any noticeable effect on overall fuel economy, however, because of the small percentage of operating time that engines in the field spend cold.

The theoretical picture painted for fuel economy is one of trade-offs. Fuel economy would be predicted to improve significantly with leaner A/F mixtures but would be predicted to decrease marginally with larger air injection systems. (EPA does not expect significant timing retard to be required to meet the 2.5 g/BHP-hr HC standard.) All of the actual emission data available to EPA show that there is a greater probability for an overall fuel economy benefit rather than a fuel economy penalty, and that the gains from leaner A/F calibrations will more than offset the losses attributable to increased air injection. The fuel economy data for Ford's and GM's prototype engines (Tables 3-1 and 3-2) show that these engines are actually more fuel efficient - with increased emission control - than they were in 1979. On the average basis, these engines are running 7-10 percent more efficient than their 1979 counterparts. Based upon this prototype fuel economy data, a modest fuel economy increase for 1985 HDGEs is anticipated relative to the 1979 baseline engines. Certainly, no aggregate fuel economy penalty is likely.

<u>Catalyst-Equipped HDGEs</u>

Little has changed with respect to the availability of information on the fuel economy effect of catalyst standards since the December 1979 Final Rulemaking. The fuel economy analysis associated with that rulemaking[10] concluded that a 4 to 9 percent improvement in fuel economy would be achieved, relative to 1979 engines, when catalysts were applied to HDGEs. This conclusion was based to a large extent on the performance of light-duty vehicles when catalysts were applied for increased emission control.

Much of the emission control required for catalyst-equipped 1987 HDGEs is being accomplished for 1985 (i.e., the first step in applying catalysts to heavy-duty engines was to reduce engine-out emission levels). As discussed above, the techniques used to reduce HDGE engine-out emissions have also yielded a fuel economy benefit. This is much of the same benefit which would have been observed had catalysts been immediately applied to HDGEs in 1985. The remaining question is how much of an incremental change in fuel economy is to be expected relative to 1985 when catalysts are applied in 1987?

Application of catalysts has traditionally removed much of the need for engine calibrations which tended to reduce fuel economy (e.g., spark retard). However, EPA does not expect the significant use of timing retard, or other engine-out emission control calibration strategies which would degrade fuel economy, to be used for 1985. Therefore, EPA does not expect the addition of catalysts in 1987 to provide much additional flexibility relative to 1985. Catalysts also create modest increases in exhaust backpressure which may somewhat decrease fuel economy; these backpressure increases, however, can be easily offset by larger diameter exhaust systems. Finally, EPA anticipates no increase in air injection rates relative to 1985 significant enough to affect fuel economy. Given the absence of major potential calibration optimizations, and given modest but correctable increases in backpressure as catalysts are applied, EPA judges that little change in vehicle fuel economy will be seen between 1985 and 1987 on account of the change in emission standards. Much of the fuel economy benefit predicted in 1979 as attributable to catalysts will already have been achieved in 1985.

Conclusions

1985 HDGEs are expected to incur a fuel economy benefit as a result of the non-catalyst standards. Prototype engine data indicates that this benefit, on average, could be as large as 7-10 percent. No net change in fuel economy relative to 1985 is expected, however, when catalysts are applied in 1987.

References

1. "Cost Effectiveness Analysis of Alternatives to 1984 Heavy-Duty Engine Emissions Regulations," General Motors Corporation, July 31, 1981.

2. "Issue Analysis - Final Heavy-Duty Engine HC and CO Standards," EPA Staff Report, EPA Public Docket No. A-81-11, March 1983.

3. "General Motors Comments on the March, 1983 EPA Staff Report Issue Analysis - Final Heavy-Duty Engine HC and CO Standards," May 6,1983.

4. "Ford Motor Company Response to the Environmental Protection Agency on Gaseous Emission Regulations for 1985 and Later Model Year Heavy-Duty Engines," May 6, 1983.

5. Letter from T. M. Fisher of General Motors, to Charles L. Gray, Jr., U.S. EPA, dated August 9, 1982.

6. "Response to Revised Gaseous Emission Regulations for 1984 and Later Model Year Light-Duty Trucks and Heavy-Duty Engines," Ford Motor Company, April 1982.

7. "Heavy-Duty Fuel Economy Program: Evaluation of Emissions Control Technology Approaches," EPA Paper No. 460/3-77-010, July 1977.

8. Letter from R. E. Bisaro of Ford Motor Company, to W. M. Pidgeon, U.S. EPA, June 25, 1982.

9. "Optimizing Engine Parameters with Exhaust Gas Recirculation," SAE Paper No. 740104, 1974.

10. "Summary and Analysis of Comments to the NPRM: 1983 and Later Model Year Heavy-Duty Engines Proposed Gaseous Emission Regulations," U.S. EPA, December 1979.

4. Issue: Allowable Maintenance

Summary of the Issue

In 1980, EPA published revised allowable-maintenance intervals for LDTs and HDEs. The primary purpose for these intervals was to encourage the design of long-life emission-related components and to limit maintenance to that which was considered technologically necessary. In the NPRM, EPA proposed to add an HDGE spark plug maintenance interval for leaded fuel, but no other specific changes were proposed. Even though the general area of allowable maintenance was not formally reopened, both LDT and HDE manufacturers submitted comments criticizing the intervals and the HDE manufacturers requested relaxation of several specific intervals.

Summary of the Comments

Light-Duty Trucks

General Motors commented that the LDT requirements were not cost effective, had no air quality benefit, and were inappropriate. It recommended that EPA drop its current requirements and adopt the LDV requirements, thus allowing GM to recommend the maintenance it believes is appropriate.

Heavy-Duty Gasoline-Fueled Engines

Heavy-duty gasoline engine manufacturers generally accepted EPA's leaded-fuel spark plug maintenance interval of 12,000 miles. However, Chrysler asked that the unleaded-fuel spark plug maintenance interval be revised from 25,000 miles to 18,000 miles, primarily because it had no data beyond that point. Ford also requested that the intervals for the EGR valve, PCV valve, heat-control valve, and checking the choke system be revised because they are also subject to lead fouling. As before with LDTs, GM stated that the allowable-maintenance intervals for HDGEs were inappropriate and should be dropped.

Heavy-Duty Diesel Engines

Several commenters stated that the allowable-maintenance intervals for HDDEs were too long. Further, the commenters contended that setting allowable-maintenance intervals for HDDEs was not necessary because heavy-duty diesel truck owners maintain their vehicles due to business reasons, and the very competitive nature of the HDDE business drives the development of more durable components. Specifically, several commenters stated that the current intervals were too long for the newly emerging medium-duty diesel engines, and in some cases were longer than the anticipated engine lifetime.

General

One general comment was received which stated that the allowable-maintenance intervals do not allow the manufacturers to recommend more frequent maintenance than that specified by the interval.

Analysis of the Comments

Light-Duty Trucks

Even though these requirements were not formally reopened for comment, EPA has carefully reviewed the comments received on the LDT allowable-maintenance requirements. Although there is clearly some disagreement between the manufacturers' and EPA's assessments of the cost effectiveness and air quality impact of these provisions, EPA finds no compelling evidence for revising these requirements.

EPA believes it is important to encourage the design and use of more durable, low-maintenance emission-related components, and believes the 1984 LDT allowable-maintenance intervals effectively accomplish this task. Adopting the current LDV requirements would be a step backwards and would do nothing toward meeting that objective. Unfortunately, there are no strong market forces acting to encourage the manufacturers to develop and use more durable, low-maintenance components.

No real data was submitted to question the technological feasibility of these requirements, and EPA continues to believe, based on its original analysis,[1] that these requirements are technologically feasible and are an appropriate and cost-effective means of improving air quality.

It is also important to note that while the new allowable-maintenance requirements are more restrictive than existing provisions in some areas, they at the same time reclassify a great deal of maintenance items as non-emission related. For these items, the manufacturers are free to recommend whatever maintenance provisions they believe are reasonable and necessary, without other regulatory requirements.

Heavy-Duty Gasoline-Fueled Engines

As with LDTs, EPA believes that allowable-maintenance intervals are necessary to encourage the use of more durable, low-maintenance emission-related components. It does not appear that market forces and business competition can be relied upon to meet the stated goal. For example, for the four HDGE manufacturers, there is a range of 6,000 miles in the manufacturers' current recommended maintenance intervals for spark plugs. This discrepancy has existed for several years, and yet there appears to be no effort on the part of the manufacturers at the lower end of the range to lengthen these intervals. It was to deal with this type of situation that the allowable-maintenance provisions were first adopted.

Turning first to Chrysler's request for a relaxation in the unleaded-fuel spark plug maintenance interval (25,000 miles to 18,000 miles), EPA notes that the sole basis for Chrysler's request is that it does not have data beyond its present interval of 18,000 miles, and thus Chrysler is uncertain about the feasibility of the 25,000-mile interval. (Two of Chrysler's three HDGE families are currently certified using unleaded fuel.)

Chrysler's request for a relaxation appears to be based primarily on a desire not to conduct any further testing, which, given EPA's goals in establishing these provisions, is insufficient reason to delete the requirement. If Chrysler decides to remain in the HDGE market after 1984, new testing will be required for development and certification. At this time, Chrysler will then have the opportunity to demonstrate compliance with the longer interval, assuming that Chrysler continues to choose emission-control technology which requires unleaded fuel.

EPA believes that the 25,000-mile spark plug maintenance interval is achievable with Chrysler's present technology. Chrysler's present LDT recommended maintenance interval is 30,000 miles. Chrysler's present heavy-duty gasoline vehicles/engines are so similar to their light-duty trucks/truck engines that compliance could be projected based almost purely on extrapolation. Chrysler's comments even indicate that it has tested some of its heavy-duty gasoline vehicles/engines on the LDT chassis-roll procedure. EPA is confident that Chrysler can meet the 25,000-mile unleaded-fuel spark plug maintenance interval with minimal effort.

EPA concurs with Ford's request that the EGR maintenance interval for leaded fuel be revised to allow one scheduled maintenance prior to 50,000 miles. Past performance of EGR systems on engines using leaded fuel leaves some doubt about the feasibility of the 50,000-mile interval before 1985 with the current level of lead used in leaded fuel. It is the judgment of both EPA and the manufacturers that the proper function of the EGR valve/system could be affected by lead deposition.

However, EPA does not agree with Ford's request for a relaxation of the 50,000-mile PCV valve interval. EPA believes that any plugging or hang-up which may occur in the valve is caused by contaminated blowby oil and not lead deposition. Ford submitted no data to support its request or its position that lead deposition is a major contributor to problems with the PCV valve. EPA believes that the 50,000-mile interval is technologically feasible and will encourage the use of durable, low-maintenance PCV valves.

Ford also requested that HDGE manufacturers be allowed to service (lubricate) their heat-control valve system once during the first 50,000 miles. (Similar systems used by other manufacturers are called early fuel evaporation (EFE).) This request was based on the tight clearances within such systems and the concern that lead buildup might hinder the free operation of the valves.

The current allowable-maintenance provisions (§86.084-25) do not specify maintenance of this type to be emission related. Therefore, the manufacturer is free to perform the maintenance as deemed necessary, provided that such maintenance is recommended to the consumer.

In a follow-up conversation on this issue Ford withdrew its request for additional choke-system maintenance.

Heavy-Duty Diesel Engines

Even though the HDDE allowable-maintenance intervals were not formally opened for comment, the EMA submitted the results of a substantial survey of fleet and owner/operator maintenance practices. EPA is always open to substantive input and data on past regulatory decisions and is considering the EMA submittal accordingly.

On its face, it appears that there is some validity to the manufacturers' contention that the business nature of the heavy-duty truck and bus industry leads to more routine maintenance than might otherwise occur, and drives the HDDE manufacturers toward continually lengthening the recommended maintenance intervals. However, the EMA report on maintenance practices tends to cast some doubt on the manufacturers' assertions that routine maintenance is the norm for HDDVs.

Tables 4-1 and 4-2 summarize the maintenance practices for the components which are currently covered by EPA's allowable-maintenance intervals.* In only a few cases was routine

* No data was submitted on diesel EGR or PCV system maintenance, presumably because neither is in widespread use on current HDDEs.

Table 4-1

Maintenance Practices -- Total Fleets
Injector Nozzles -- Function Incidence Rates*

Item	Total Fleets**	GVW 8	GVW 7-6	Fleet Size 3-49	Fleet Size 50+	Usage Long Haul	Usage Other	Owner/ Operator
Clean/Recalibrate/Check:								
Perform Routine Maintenance (%)	46	48	35	46	44	55	41	34
Routine Maintenace Interval (miles) (x 1,000)	88	89	81	85	100	87	89	98
Perform Maintenance Upon Failure (%)	53	52	62	53	54	44	58	66
Replace:								
Perform Routine Maintenance (%)	21	23	15	19	29	24	19	21
Routine Maintenance Interval (miles) (x 1,000)	143	153	93	143	145	178	111	155
Perform Maintenance Upon Failure (%)	78	77	83	80	69	76	80	79

* Routine and failure maintenance do not always sum to 100 percent due to responses which fell in neither category.

** Does not include owner/operator, which is considered as a separate group in this study.

Table 4-2

Maintenance Practices -- Total Fleets
Turborcharger - Function Incidence Rates*

Item	Total Fleets**	GVW 8	GVW 7-6	Fleet Size 3-49	Fleet Size 50+	Usage Long Haul	Usage Other	Owner/ Operator
Rebuild:								
Perform Routine Maintenance (%)	27	30	16	27	29	31	24	44
Routine Maintenance Interval (miles) (x 1,000)	201	207	149	211	169	190	219	124
Perform Maintenance Upon Failure (%)	64	61	75	63	66	56	70	56
Replace:								
Perform Routine Maintenance (%)	11	11	14	11	14	8	13	26
Routine Maintenance Interval (miles) (x 1,000)	154	179	81	121	182	61	183	135
Perform Maintenance Upon Failure (%)	79	79	79	78	82	76	81	74

* Routine and failure maintenance do not always sum to 100 percent due to other responses which fell into neither category.

** Does not include owner/operator, which is considered as a separate group in this study.

maintenance conducted half the time or more, and in virtually no cases could routine maintenance be considered dominant. In short, the data submitted by EMA tend to refute its contention that allowable-maintenance intervals for HDDEs are not necessary due to good maintenance practices by heavy-duty truck owners.

However, the data submitted by EMA provide some useful information on the average-mileage intervals followed by those users who do perform routine maintenance. Even though there are some substantial disparities among the intervals followed by the various HDDE users, the data are useful for comparing the length of the EPA allowable-maintenance intervals against current field practices as represented by the EMA data.

The EMA data show that EPA's allowable-maintenance interval for cleaning of injector tips is generous. EPA's interval is 50,000 miles, and the EMA data indicate a fleet-average value of 88,000 miles, and an owner/operator average value of 98,000 miles.

EPA currently has an allowable-maintenance interval of 200,000 miles for replacement of injectors. Data submitted by EMA indicate a wide range of values in current practices. Intervals tend to be lower for Gross Vehicle Weight Rating (GVWR) Classes VI and VII trucks or non-long haul applications (93,000-111,000 miles), and higher for GVWR Class VIII trucks or fleets involved in long-haul applications (153,000-178,000 miles). For owner/operators the average-mileage interval is 155,000 miles. These data indicate that EPA's interval is too stringent, especially for the HDDE class as a whole. An interval of 200,000 miles might be reasonable for engines designed for long-haul/Class VIII trucks, but is probably too stringent and not as cost effective for less durable engines. A revision of the current EPA interval appears appropriate if one interval is to serve for the entire HDDE class. In this case, setting a revised interval of 150,000 miles seems appropriate based on the EMA data.* This would tend to extend the intervals in the cases where routine maintenance appears least prevalent (and the intervals are shortest), and would extend the intervals on average for the total fleet. EPA believes an interval extended to 150,000 miles is feasible for HDDEs, including those used in Classes VI and VII trucks.

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* Also, in a December 1980 study prepared by a task force of the American Trucking Association, forty respondents to its survey indicated a mean injector replacement interval of 170,125 miles. The range in values was 50,000-375,000 miles, the median was 150,000 miles, and the mode was 100,000 miles.

The EMA data also address the area of turbocharger rebuild/replacement. The EMA data show that rebuilds are far more prevalent than replacement, and that replacements tend to occur as a result of catastrophic failure instead of routine maintenance. As before with injectors, EPA's current interval of 200,000 miles for rebuild of turbochargers appears reasonable for GVWR Class VIII trucks used in fleets in most applications (169,000-219,000 miles), but might be too stringent for GVWR Classes VI and VII trucks and owner/operators (124,000-149,000 miles). EPA's interval of 200,000 miles also covers the replacement of turbochargers. The EMA data are not as useful here because of the heavy dominance of non-scheduled maintenance practices. Even so, it is evident that when replacement does occur, it is at shorter intervals than rebuilds. Considering the EMA data, EPA believes that a revision of the turbocharger rebuild/replacement interval is appropriate. Setting the interval at 150,000 miles would accomplish the goals of the allowable-maintenance program, while at the same time serving as a reasonable compromise value for the rebuild of GVWR Classes VI and VII truck turbochargers and the average fleet interval for replacement. EPA also believes that there is a greater likelihood that the turbocharger maintenance will be performed because of the likely negative performance and fuel economy impacts.

In summary, EPA continues to believe that the allowable-maintenance intervals are necessary for HDDEs, because routine maintenance of emission-related items is not as prevalent as claimed by the HDDE manufacturers. EPA's goal is to certify HDDEs under maintenance intervals that reflect the actual in-use maintenance schedule as closely as possible. However, EPA does see some validity to the manufacturers' contention that the competitive nature of the HDDE business will tend to provide an impetus to lengthen recommended maintenance intervals and to improve general component durability. Relaxing the allowable-maintenance intervals for the two components discussed above is appropriate, because the data submitted tend to indicate that the technologically necessary intervals set by EPA in 1980 are too long for the HDDE class as a whole. The intervals set in 1980 are reasonable for engines used in Classes VII-VIII long-haul trucks, but appear too stringent for less durable medium-duty diesel engines designed for trucks in GVWR Class VI and below. If one interval is to serve for the entire HDDE class then it may by necessity have to be shorter than is technologically necessary for Classes VII-VIII trucks/engines.

General

One commenter claimed that the allowable-maintenance intervals preclude the manufacturers from recommending more frequent maintenance than permitted by EPA. This is not the case. Manufacturers may recommend maintenance at more frequent intervals if they desire, but any maintenance beyond that prescribed by the allowable-maintenance intervals cannot be tied to emission warranty eligibility.

It is also important in this context to remember that, as stated earlier, EPA's allowable-maintenance requirements apply only to emission-related maintenance. Manufacturers are allowed to recommend any maintenance intervals that are reasonable and necessary for non-emission-related maintenance.

Conclusions

1. No changes will be made to the LDT allowable-maintenance provisions.

2. EPA has decided to include an HDGE leaded-fuel spark plug maintenance interval of 12,000 miles, but not to revise the present unleaded-fuel interval.

3. A leaded-fuel EGR valve/system maintenance interval for HDGEs which allows servicing at 24,000 mile intervals will be included.

4. The PCV maintenance interval for HDGEs will not be revised.

5. The injector replacement and turbocharger rebuild/replacement intervals for HDDEs will be reduced, from 200,000 to 150,000 miles.

References

1. "Summary and Analysis of Comments in the Proposed Rulemaking for Gaseous Emission Regulations for 1983 and Later Model Year Light-Duty Trucks," U.S. EPA, OANR, OMS, ECTD, SDSB, May 1980.

5. Issue: Minor Amendments to HDE/LDT SEA

Summary of the Issue

On January 13, 1982, EPA proposed several technical and procedural amendments to the regulations governing Selective Enforcement Auditing (SEA) of HDEs and LDTs contained in Subparts A, K, and N. These regulations were originally promulgated for HDEs at 45 FR 4167 and 4170 (January 21, 1980), and were updated on September 25, 1980 to include LDTs at 45 FR 63767 and 63772.

These amendments were intended to clarify specific aspects of the existing regulations, to improve the efficiency with which the HDE/LDT SEA program will be conducted in the future, and to reduce the compliance burden on the affected manufacturers where practical. Through these amendments, EPA expects the HDE/LDT manufacturers to accrue substantial cash expenditure and cash flow savings.

Summary and Analysis of the Comments

The HDE/LDT manufacturers did not have many major concerns with the amendments to the HDE/LDT SEA procedures. The manufacturers did however, raise numerous minor issues pertaining to various technical points and details of the amended, as well as the original HDE/LDT SEA procedures. The majority of these comments came from General Motors (GM), who stated that its proposal was a resubmittal of its earlier comments (submitted on the HDE NPRM which was promulgated as a final rule on January 21, 1980) on the subject of Subpart K. Therefore, this entire summary and analysis is dedicated to the new comments on the technical and procedural SEA amendments as well as GM's resubmittal of its original comments regarding the HDE/LDT SEA procedures.

The comments received fall into a number of subissues. Each of these subissues will be treated separately.

a. Applicability (§86.1001-84).

GM suggested that this section include a provision to allow a phase-in period for trial test orders for heavy-duty engine (HDE) SEAs. "A minimum period of one year, after the first Heavy-Duty engines are certified on a new test cycle, is recommended."

On January 13, 1982, EPA proposed several regulatory relief initiatives related to the HDE/LDT industry. One of these initiatives was a two-year delay in the start of the HDE SEA program until 1986. The two-year delay in the HDE SEA program already satisfies GM's concern of a phase-in period of one year after the first HDEs are certified on a new test cycle (gas and diesel HDEs are scheduled to be certified on a new transient test cycle in the 1985 model year, with optional transient test standards for the 1984 model year).

In addition, the Agency will make its SEA personnel available, to the extent possible, to monitor trial SEAs prior to the 1986 model year (anytime in the 1985 model year). Any HDE manufacturer that is interested in conducting a trial audit, pursuant to the provisions of Subpart K, may contact EPA in writing to make the appropriate arrangements. Also, the Agency prefers that any manufacturer requesting a trial audit invite other HDE manufacturer representatives to observe the audit in order to maximize its usefulness. These trial audits are designed to provide both the manufacturers and EPA with logistical and procedural experience in running the new SEA program and will be performed on a voluntary basis.

b. Definition of "Configuration" (§86.1002-84(b)).

The present regulations state that a HDE/LDT configuration will be "...described on the basis of...other parameters which may be designated by the Administrator." GM contested this definition as being unreasonably broad and vague and wanted protection against arbitrary selection of parameters by EPA.

This provision about "other parameters" is similar to a provision contained in the present LDV SEA definition of "configuration" (when the present LDV regulations or program are mentioned henceforth, they also include LDTs until the 1984 model year). A LDV configuration has never been defined beyond the specific parameters contained in that definition.

Present HDE/LDT configurations can be described using the specific parameters in the HDE/LDT definition. However, EPA needs some flexibility in specifying configurations, because new emission control technologies developed in response to 1984 and later HDE standards may result in emission control parameters not presently identified. EPA does not intend to use this flexibility in an unreasonable manner but has retained the proposed definition in the final rule.

c. Test Orders - Instructions in test order (§86.1003-84(b)).

GM stated that the phrase "...instructions in the test order.", in the last sentence of paragraph (b), be eliminated as redundant and unnecessary in that the Clean Air Act (the Act) mandates compliance with test orders issued under the regulations. EPA prefers not to delete the phrase because it alerts the manufacturer of their obligations directly in the regulations under Subpart K.

d. Test engine or vehicle selection procedures in the test order (§86.1003-84(c)).

Present regulations state that "The test order will specify... the procedure by which engines or vehicles of the specified configuration must be selected." General Motors believes that this provision is too vague and ambiguous;

it stated that the test sample selection process should be standardized and placed in the regulations. In addition, General Motors recommended revising this provision to ensure engines or vehicles are selected in a quantity not to exceed that required to meet testing schedules while not disrupting normal production activities.

It is not possible to standardize the test sample selection procedure because of the varying production practices and assembly plant operations of the different HDE/LDT manufacturers. This conclusion is based on visits by EPA personnel to domestic HDE/LDT manufacturers and EPA's experience with the LDV SEA program. Also, the sequential sampling plans were designed to prevent severe disruption of a manufacturer's production and customer delivery schedules. The impact on these schedules should be minimized because these sampling plans allow configurations to be tested as expeditiously as possible and the test engines or vehicles may even be selected over several days. It should be emphasized that paragraph §86.1007-84(a) allows for manufacturer input into the determination of the appropriate test sample selection procedure. Therefore, EPA has made no changes in its proposed statement for the final rule.

e. Other standardized test order instructions (§86.1003-84(c)).

The current regulations state that "In addition, the test order may include other directions or information essential to the administration of the required testing." General Motors stated that the latitude allowed EPA by this provision is too broad, and that any instructions which can be standardized should be placed in the regulations and any information which is deemed "essential" should also be included. EPA determined that some of the specific instructions presently incorporated in LDV SEA test orders are applicable to HDE/LDT SEA testing and included them in the January 21, 1980 final rule as new paragraph §86.1003-84(c)(2). However, the provision to include "other directions or information" essential to administer SEA testing has been retained to allow some flexibility in SEA operating procedures. This flexibility can be in both the interest of the manufacturers and EPA, as it will allow audits to be conducted in the most expeditious manner practical, given circumstances unique to a particular manufacturer.

The latitude built into the test order and sample selection sections of the SEA regulations is intended to accommodate procedural variations, especially in the area of test engine selection. Specific instructions may be made to minimize the impact on each manufacturer's normal production activities while still assuring the generation of accurate, representative test results.

f. Selection at non-preferred plants (§86.1003-84(d) and §86.1007-84(a)).

The current regulations assert that, even though a manufacturer has submitted a list of assembly plants preferred for engine or vehicle selection, "...the Administrator may order selection at other than a preferred location." GM stated that this paragraph should be revised to ensure that selection is performed at non-preferred locations only if it will not disrupt normal production activities and only upon making the determination that evidence exists indicating a noncompliance at other than the manufacturer's preferred plant. The sequential sampling plans contained in this regulation were designed to allow flexibility in sample selection to prevent, to the greatest extent possible, disrupting a manufacturer's normal production and delivery schedules. EPA intends to select test engines and vehicles at preferred locations, but requires the flexibility of selecting at non-preferred plants when that would allow the audit to be performed expeditiously or permit the auditing, based upon available evidence, of specific cases of noncompliance. For example, in the LDV SEA program, audits have had to be canceled or significantly delayed due to the preferred plant being down for a couple of weeks, closed indefinitely, or otherwise unavailable for selection. In such cases, the Agency needs to be able to select its test engines or vehicles at non-preferred plants. To retain this flexibility, EPA made no change to the final rule.

q. Additional test orders for noncompliance (§86.1003-84(f)(3)).

EPA provided that after the annual limit has been met, the Administrator may issue additional test orders for which evidence of noncompliance exists. General Motors argues that test orders should not be indiscriminantly and unreasonably issued on the basis of "any evidence." Further GM says, test orders when issued, should count against the annual limit the same as any other test order. Otherwise, the "annual limit" would be open ended and the manufacturer would be subject to an indefinite number of test orders.

EPA has a responsibility to investigate those engine configurations for which it has evidence of noncompliance, and, therefore, has not incorporated this provision into the regulations. Also, this provision is consistent with the present LDV regulations. The Agency is however, sensitive to GM's concern that manufacturers may be subjected to an indefinite number of test orders. Based on evidence of noncompliance, a test order issued within the annual limit will count toward the annual limit, if the configuration passes the audit. If the limit has been reached, additional test orders may be issued only on the basis of evidence of noncompliance. In addition, the provision requiring a statement of the reason for issuance of a test order beyond the annual limit will be retained.

h. Discrepancies between EPA test results and manufacturer test results (§86.1004-84(b) and (c)).

The present regulations state that EPA's test results comprise the official data for a test engine or vehicle when there is a disagreement with a manufacturer's results. GM disagrees with the assumption that the manufacturer's test facility is deficient and that it bears the burden of proving that its own data are correct. It argues that the certificate of conformity should not be suspended with respect to the vehicle or engine configuration in question until the reasons for the lack of correlation are determined. However, the regulations provide two mechanisms for resolving differences between data: (1) paragraph §86.1004-84(c)(2) allows a manufacturer to demonstrate that EPA's data were erroneous and its own data were correct; and (2) if EPA invokes a suspension of the certificate of conformity based on the Administrator's test data, the manufacturer can request a hearing under paragraph §86.1012-84(l) to determine whether the tests were conducted properly. Therefore, this provision is unchanged.

i. Retaining names of involved personnel (§86.1005-84(a)(2)(iii) and (a)(2)(iv)).

Paragraph §86.1005-84(a)(2)(iii) requires the manufacturer to retain the names of all personnel involved in the conduct of an audit and paragraph §86.1005-84(a)(2)(iv) requires the manufacturer to retain the names of all personnel involved in the supervision and performance of a repair. GM proposed that these provisions be deleted because this information is unnecessary and irrelevant for EPA's needs and the information goes beyond that required by the current LDV/LDT regulations.

EPA does agree that these provisions should be consistent with the requirements of the present LDV/LDT regulations which only require the names of supervisory personnel be retained by the manufacturer. Further, EPA believes that the names of manufacturer personnel involved in repairing vehicles or engines and conducting audits can be obtained from supervisory personnel if an investigation of an audit is ever necessary. Therefore, EPA revised paragraphs §86.1005-84(a)(2)(iii) and (a)(2)(iv) to reflect GM's comment of consistency with the LDV/LDT regulations.

j. Requirement for submitting manufacturer's test results (§86.1005-84(c)).

This paragraph requires manufacturers to submit to EPA their own production engine or vehicle test data. GM characterized this requirement as unnecessarily burdensome and unreasonable, wanted a semiannual reporting period (instead of quarterly), wanted to submit only complete Federal Test Procedure (FTP) data from an established quality audit program, proposed to delete the requirement for submitting data on Automatic Data Processing (ADP) equipment, and recommended various revisions and deletions in the required information.

Subpart K does not impose any requirement that a manufacturer conduct an internal quality audit program, but if a manufacturer does conduct such a program, Section 208(a) of the Act authorizes the Administrator to require the submission of these data to EPA. The data may be used to help determine compliance of HDEs or LDTs with applicable emission standards. In addition, Subpart K does not require the manufacturer to submit emission test results on ADP equipment. What the provision says is _if_ emission test results are available on ADP equipment and the manufacturer's storage device is compatible with EPA's ADP equipment, then the manufacturer would submit the information in a form available for automatic processing. EPA will even furnish the necessary ADP storage devices upon a manufacturer's request.

This submission of test data requirement has been proven workable in the current LDV SEA program and does not appear to be unreasonably burdensome to manufacturers. EPA believes that the reporting period (quarterly) and requirements it promulgated for the HDE/LDT manufacturers are reasonable and are similar in scope to those currently being met by LDV/LDT manufacturers. A semiannual reporting period, with closing dates of January 31 and July 31 (as suggested by GM), would not adequately meet EPA's needs. Emission's data received so late in the model year (the first reporting period's data would not be received until late February or early March and the last reporting period's data would not arrive until the end of the model year) would provide the Agency with little help in determining compliance of HDEs and LDTs with applicable emission standards. The manufacturer is required to describe the emission test used to obtain the data submitted (see §86.1005-84(c)(1)) to help EPA evaluate the value of the data when compared to the FTP. EPA, therefore, proposes no changes to §86.1005-84(c).

k. Additional information which the Administrator may require (§86.1005-84(e)).

GM recommended deleting this requirement because it is ambiguous, provides unlimited discretion to the Administrator, and goes beyond the scope of Section 208(a) of the Clean Air Act (GM also recommended that §86.1009-84(d)(5)(vi) be deleted for similar reasons). EPA however, has made no changes to these paragraphs for the final rule because the Agency needs some flexibility in requiring information on a case-by-case basis. Paragraph §86.1005-84(e) states that the Administrator may request information not specifically provided under the other sections of §86.1005-84. However, the Administrator is still bound by Section 208(a) to require only the information that will enable a determination to be made of whether a manufacturer has acted or is acting in compliance with Title II, Part A of the Clean Air Act and the regulations promulgated thereunder.

l. Entry and access (§86.1006-84(b)(4)).

In this paragraph, GM recommended that only "emission related" parts or aspects of an engine or vehicle be investigated, but it did not give a reason for this comment. §86.1006-84(a) states that matters related only to this subpart (Subpart K) will be investigated. Therefore, EPA has not revised §86.1006-84(b)(4) in response to this comment.

m. Entry and access (§86.1006-84(h)(3)).

GM recommended that this paragraph be revised in order to more accurately reflect the current practice of the LDV regulations. Paragraph (h)(3) of §86.1006 deals with the definition of "operating hours" at facilities or areas other than those where engine or vehicle storage is concerned. EPA concurs with GM's comment and has amended §86.1006-84(h)(3) to be consistent with the LDV regulations, for purposes of uniformity and clarity.

n. Authorization for personnel appearance and entry without 24 hours notice (§86.1006-84(h)(4) and (5)).

GM recommended that paragraph §86.1006-84(h)(4) be amended and a new paragraph §86.1006-84(h)(5) be added to require the Assistant Administrator for Air, Noise, and Radiation to approve these authorizations. EPA believes it is unnecessary to require the Assistant Administrator to authorize either appearances of personnel or entry without 24 hours prior notice because these authorizations can be performed by other responsible Agency officials. If a manufacturer refuses to consent to personnel appearance or entry without 24 hours notice, EPA is required to seek a search warrant before attempting to conduct these activities.

Therefore, no changes relating to these issues have been made in the final rule.

o. Selection of incomplete test engines or vehicles (§86.1007-84(b)).

The present regulations state that a test order will specify the manner in which assembly of incomplete test engines or vehicles will be completed. GM recommended that this provision be revised to allow the assembly to be completed according to applicable production and assembly quality control methods and procedures. GM first proposed this revision during the initial comment period on the HDE gaseous emission regulation notice of proposed rulmaking (NPRM). EPA agreed with the request and amended paragraph §86.1007-84(b), in the January 21, 1980 HDE final rule, to allow the use of these methods. However, EPA qualified GM's suggestion by adding that the procedures must be "documented by the manufacturer" and eliminated GM's suggested phrase, "assembled to normal certification dress." These qualifications were necessary to ensure that engines are assembled using only standard assembly line procedures and quality control checks and that these test engines duplicate, as closely as possible, the configuration of the manufacturer's engines being distributed into commerce. EPA continues to believe such documentation is important and will retain paragraph §86.1007-84(b) as is.

p. Exception to sample selection (§86.1007-84(c)).

GM proposed that the last portion of this paragraph be clarified and rewritten to include an exception that the Administrator may approve a modification in the normal assembly procedures. Although GM did not describe a situation in which such an exemption would be needed, the comment has been adopted.

q. Allowance for "dealer preparation" procedures (§86.1008-84(b)(1)).

GM recommended that an additional paragraph be added to the end of this section to reflect the current practice of the LDV regulations. The recommended new paragraph states that a manufacturer may perform "dealer preparation" procedures on the new vehicles or engines, provided that these procedures are documented in written instructions or are approved by the Administrator in advance of their performance. EPA believes that SEA vehicles or test engines that have undergone dealer preparation procedures will represent "real world" conditions to the extent that these procedures are actually and correctly performed by dealers. EPA's experience with LDVs indicates that in several cases, dealer preparation procedures are not performed, or are not performed correctly by the dealers. However, the current regulations do permit dealer preparation procedures to be performed if they are approved in advance by the Administrator. EPA approval will be facilitated if the manufacturer provides sufficient dealer survey data or other information to allow EPA to conclude that the procedures are actually being correctly performed by dealers. Therefore, EPA did not alter this provision.

r. Service accumulation requirements (§86.1008-84(c)(1)).

The current EPA regulations require that service accumulation prior to engine testing be performed at a minimum rate of 16 hours per 24 hour period, unless otherwise approved by the Administrator. GM proposed an 8 hour minimum rate to make this requirement more consistent with the LDV regulations, which does not require the manufacturer to maintain a two shift operation at a test facility. GM did not justify on a technical basis why test engines could not be run for a minimum of 16 hours per day. The Agency would like to conduct the audits in the most expeditious manner possible. We believe that this is still a reasonable requirement because HDE service accumulation does not require a full-time "driver" and can be monitored automatically for emergency shut-down. In addition, there is an existing provision in this paragraph of the regulations that allows the Administrator to approve an alternate service accumulation rate based on a justifiable manufacturer request. Therefore, EPA has not made a revision to this paragraph in the final rule.

s. Test per day requirement (§86.1008-84(g)(1)).

GM recommended that EPA's requirement of a minimum of two SEA tests per 24 hour period be revised to one test per 24 hour period on the average. GM proposed this change to make this regulation consistent with current LDV requirements. GM stated that the LDV regulations require only the use of a single test cell for the expeditious completion of an audit, whereas, for HDEs the manufacturer would have to dedicate two test cells for the purpose of an audit.

In its HDE SEA program, EPA desires to conduct the audits in as expeditious and non-disruptive a manner as possible while still obtaining accurate test results. Based on the time required to perform the transient test procedure, taking into account the "forced cool-down" allowed in the final rule (see Subpart N), EPA has determined that two tests can be performed in a 24 hour period, given two test cells (especially with double-ended dynomometers). EPA used this test cell requirement in its analysis of the cost of these regulations. To require only one test per day would make the SEA last about twice as long, with resultant demands on both the manufacturer's and the Agency's resources. If a manufacturer has a justifiable reason for being unable to perform the minimum number of tests, the regulations allow them (under §86.1008-84(g)(4)) to ask EPA for a reduction. EPA has therefore made no change in the test per day requirement in this paragraph for the final rule.

t. Option to retest (§86.1008-84(i)).

GM wanted EPA's present regulation revised to allow retesting at any time during an audit (as opposed to only after a fail decision has been reached) and to delete the requirement for testing each engine or vehicle the same number of times. It justified these changes on the basis of possible logistic, storage, and economic impacts on manufacturer operations and comparability with the LDV SEA regulations. To permit a manufacturer to retest, before an actual failure has occurred, may unnecessarily delay the audit and may even cause the negative impact on operations that GM wished to avoid. There is nevertneless, an existing provision in this paragraph that allows the Administrator to approve retesting, before a fail decision has been reached, based on a manufacturer's request accompanied by a satisfactory justification. However, the engines or vehicles must still be tested the same number of times. To permit retesting of only failed engines or vehicles or to allow some engines or vehicles to be tested more times than others will bias the test results from a statistical viewpoint because of inherent test-to-test variability. EPA has therefore made no changes to this paragraph for the final rule.

u. Failed engine or vehicle report (§86.1012-84(i)(2)).

GM proposed that this paragraph be changed to delete the requirement that a written report to the Administrator be submitted within five working days after successful completion of testing on a failed vehicle or engine. GM stated that this change will more accurately reflect the current requirement of the LDV regulations.

In the original HDE/LDT NPRMs, EPA proposed regulations that required the written report on corrective testing of engines or vehicles that failed emission testing during an SEA be submitted to EPA within five working days after completion of that testing. While EPA needs to receive reports on the repair of noncomplying engines or vehicles in a timely manner, the Agency acknowledges that corrective action need not be taken immediately after an engine or vehicle failure. To clarify its intent, EPA revised this paragraph (in the January 21, 1980 and September 25, 1980 final rules) so as not to limit the time a manufacturer may take to complete testing of failed engines or vehicles. The Agency also concurs with GM's statement that this paragraph be changed to reflect the current requirements of the LDV regulations, which do not require a five working day time limit for submission of failed vehicle reports. EPA will revise paragraph §86.1012-84(i)(2) to relect GM's comment and the LDV regulations.

v. Applicability (§86.1001-84).

American Motors (AM) commented that the applicability in §86.1001-84 was not changed to reflect the deletion of HDEs for the 1984 model year, and that LDTs are still included in §86.601 applicability (Subpart G). AM goes on to say that EPA could avoid much confusion and simplify the regulation by continuing the requirements of Subpart G for LDTs until such time as EPA requires HDE SEAs (1986 model year). AM opposes grouping LDTs with HDEs for any emission certification or compliance related matters. Therefore, it recommends postponing the applicability of Subpart K until 1986.

On January 21, 1980, EPA promulgated gaseous emission regulations for 1984 and later model year HDEs and a similar rulemaking affecting 1984 and later model year LDTs was promulgated on September 25, 1980. The primary function of these rulemakings was to promulgate the statutory HC and CO standards called for in the 1977 Clean Air Act Amendments (202(a)(3)(A)(ii)). In addition to the statutory standards these rulemakings implemented a number of other provisions to be effective for the 1984 model year, such as: sequential sampling plans for SEA, revised certification requirements, a revised useful life definition, and an idle test and idle emission standard for gasoline-powered LDTs and HDEs.

These new requirements for LDTs and HDEs were promulgated simultaneously to avoid the procedural disruption and waste associated with frequent changes in emission regulations. The Agency chose this comprehensive approach to controlling LDT and HDE emissions because it was the most efficient approach in that it allows the manufacturers to deal with the effects of several regulations at once. This will avoid repeated financial outlays for research, development, recertification, and retooling.

The applicability of §86.1001-84 (Subpart K) was not changed to reflect the deletion of HDE SEAs for 1984 because the regulations still apply for 1984 and later model year HDEs and LDTs (LDTs are still subject to SEAs under Subpart K starting in the 1984 model year - LDTs are currently subject to SEAs under the provisions of Subpart G). The Agency, as part of their regulatory relief initiative, has made a commitment to the HDE manufacturers not to begin the HDE SEA program until the 1986 model year. In addition, Subpart K will be used to implement the nonconformance penalty (NCP) provisions of Section 206(g) of the Act, which, where applicable, may apply to LDTs (greater than 6000 pounds GVW) as well as HDEs. As far as §86.601 (the applicability provision in Subpart G) is concerned, LDTs are still included because this provision for LDTs is effective through the 1983 model year. In another EPA rulemaking, we intend to propose several changes to Subpart G to provide greater consistency with Subpart K. That proposal would make the sampling plans, test procedures, etc. coincide for LDTs and LDVs. Therefore, EPA has not revised paragraphs §86.601 or §86.1001-84 in response to these comments.

6. Issue: Split Standards - Gasoline-Fueled vs. Diesel Engines

Summary of the Issue

Virtually all HDVs are powered by either gasoline- or diesel-fueled engines. In the past, the gaseous exhaust emission standards for each pollutant (i.e., HC, CO, NOx) have been the same for all HDVs regardless of the type of powerplant used in the vehicle. This has been true even though the two types of powerplants have different operating characteristics, which lead to significantly different levels of the various pollutants in the uncontrolled case. Diesel engines are inherently low in HC and CO, while being relatively high in particulates. Gasoline-fueled engines are relatively high in HC and CO but inherently low in particulate. Both types of engines produce similar levels of NOx in the uncontrolled case, but gasoline engine NOx is more easily controlled.

In the past, emission standards were of a level of stringency such that both types of engines could meet them with relative ease. However, as tighter emission standards are considered for the future, the difference in inherent emission levels between the two types of engines may need to be considered. An emission standard which is a practical lower limit for one type of engine may be quite a high level of emissions for the other type of engine. By setting separate standards for the two types of powerplants, the maximum degree of emission reduction might be obtained for all pollutants in a cost-effective manner.

At the February 18, 1982 public hearing, for this rulemaking as well as in its March 23, 1982 notification extending the comment period, the Agency requested comments on this issue of setting separate standards for gasoline- and diesel-fueled engines. The comments received are summarized and analyzed below.

Summary of the Comments

EPA received comments from seven HDV manufacturers and one trade association on this issue. The seven manufacturers were: Caterpillar Tractor Company, International Harvester Company (IHC), Chrysler Corporation (Chrysler), Mack Trucks (Mack), Daimler-Benz A.G., General Motors Corporation (GM), and Ford Motor Company (Ford). The trade association was the Engine Manufacturers Association (EMA). Only one major domestic engine manufacturer, Cummins Engine Company, provided no position on this issue.

Caterpillar recommended "...the complete separation of HD diesel regulations from HD gasoline regulations." Caterpillar stated that it would not be opposed to a less stringent HC standard for gasoline-fueled HDVs as compared to the diesel standard, but it requested that similar consideration be given to future NOx standards.

International Harvester Corporation stated that the standards mandated by the 1977 amendments to the Clean Air Act (CAA) are not feasible when the need to avoid excessive cost and fuel economy losses is considered. Therefore, IHC recommended that the Agency revise all of these standards to utilize the best control technology while minimizing costs. IHC recommended that "...in the future EPA should set standards based upon best and most cost-effective emission control technology taking into consideration the type of basic engine (diesel or gasoline)." IHC did not oppose the concept of split standards.

Chrysler stated that it saw no compelling reason for EPA to consider establishing separate standards that would be applied to comparable vehicles performing similar operations. Chrysler claimed that the CAA made no provisions for separate standards for different types of engines. It quoted from §202(a)(3)(A), which authorizes the Administrator to establish classes based on "gross vehicle weight, horsepower, or other factors as may be appropriate," but Chrysler claimed the legislative history is clear that the use of diesel fuel is not a proper determinant for establishing a separate class of engines.

Mack stated at the public hearing that since gasoline engines are not in competition with its diesels, it has "...no problem with a different standard for gasoline." Mack also expressed a hope that "similar concessions might be in the cards for the diesel should they be needed," with regard to future NOx or particulate standards.

Daimler-Benz agreed with EPA that "...the Clean Air Act permits the establishment of separate standards for diesel and gasoline engines based on the technical capability of each engine class." Furthermore, Daimler-Benz claimed that it is appropriate to establish separate standards for all regulated pollutants.

General Motors stated that it did not believe separate standards should be established for gasoline-fueled vs. diesel-fueled engines, and gave three main reasons to support its position. First, GM commented that the cost of control increases sharply as the lowest achievable levels are approached. As these low level of emissions are approached, setting different standards of approximately equal stringency would become very difficult. Therefore, a competitive advantage would be artificially induced for one or the other engine type.

Second, GM stated that there would be little incentive to develop a less costly, low-emission powerplant of new technology which would be capable of complying with given HDE emission standards if it is likely that after introduction that engine type would be subjected to more stringent standards based on the best available control technology for that engine. The new engine's original cost advantage over other available powerplants would be eroded.

Third, GM claimed that Congress intended one set of standards to cover both engine types. GM quoted the House report which accompanied the 1977 CAA amendments as saying, "In permitting the Administrator to specify separate classes or categories of vehicles or engines, the Committee did not intend to authorize the Administrator to prescribe separate standards for gasoline-powered and diesel-powered engines." Furthermore, GM claimed that the standards which are specified in CAA §202(a)(3)(A)(ii) are to apply to all heavy-duty engines.

General Motors was also concerned that if separate standards were promulgated someone might erroneously conclude that the diesel HC and CO standards should be 90 percent reductions from uncontrolled diesel levels. GM claimed such levels would in some cases be infeasible, thus resulting in unnecessary and expensive regulatory activity to periodically revise the standards as required by the CAA.

Finally, GM noted that EPA discussed the issue in the Advance Notice of Proposed Rulemaking (ANPRM) for LDT/HDE NOx (46 FR 5838). The ANPRM took the position that the same NOx standard should apply to both types of engines within a given class. GM also pointed out EPA's reasoning that it would be inequitable to establish different requirements for competing engines within the same class and that to do so could have the appearance of favoring one powerplant over another. GM stated that EPA's reasoning expressed in the NOx ANPRM is equally applicable to the HDE HC and CO standards.

Ford claimed that "...the public interest is best served by the establishment of uniform standards for competing classes of vehicles." Since Ford did not elaborate on the above statement, we will assume that Ford's comment was concerned with the competitive effects similar to those expressed in GM's comments.

Ford also claimed that EPA does not have statutory authority to set separate standards for gasoline- and diesel-fueled HDEs. Ford quoted from the 1977 report by the

Senate Committee on Environment and Public Works which accompanied Senate Bill 252. The Committee stated, "Diesel vehicles, which inherently emit less hydrocarbons and carbon monoxide, must meet the standards set for gasoline-powered vehicles." Also, Ford submitted the same quote from the House Committee on Interstate and Foreign Commerce that GM submitted.

Ford claimed that Congress' intent to establish uniform standards is further evidenced by the fact that Congress did allow some separate standards, but it did so in a very limited and specific fashion. For example, unique NOx standards for 1981-84 diesel-powered light-duty vehicles (LDVs) that qualify for waivers, and waiver provisions for "small manufacturers" and "innovative technology," are specifically authorized.

Finally, Ford stated that EPA itself has recognized the need for uniformity of standards. Ford, as did GM, pointed out EPA's intention to propose a NOx standard for all HDVs that represents the level that can be achieved by diesel engines. Ford claimed that this same uniformity must apply to all standards.

The Engine Manufacturers Association recommended that the Agency propose a rule in response to which interested parties could comment. EPA should consider how separate standards might correct the problems created by the statutory NOx standard which the Agency "...has already indicated it believes is not technologically feasible." EMA suggested that EPA consider the establishment of future standards based on more representative baselines or control technologies. EMA stated that it would submit additional comments at such time as the Agency articulates a policy which addresses the issues.

Analysis of the Comments

The four commenters who produce only HDDEs stated that EPA could set separate standards for the two engine types. In fact, most of these commenters urged EPA to do so. These commenters felt that split standards were consistent with that requirement in the CAA for EPA to consider the impact of available technology in setting standards.

General Motors, Ford, and Chrysler all produce HDGEs, and all were opposed to split standards. GM also produces HDDEs. Three reasons for opposition were common to both GM and Ford: 1) competitive effects, 2) statutory intent, and 3) EPA precedent. Chrysler's main reason for opposition was statutory intent. Each of these will be discussed in the order given, followed by discussion of the other two concerns of GM (i.e., infeasibility of 90 percent reduction and incentives for new technology).

EPA agrees with the commenters that the possibility of a competitive advantage being established does exist. This situation might occur if the Agency attempted to set standards at the very lowest possible emission limits of the two engine types. Since the cost of control often increases rapidly as such limits are approached, great care would need to be taken to assure that such separate standards would not lead to an unreasonable cost differential for the two engine types. (This clearly would not apply in cases such as evaporative HC or particulate/smoke standards, where only one engine type is regulated.)

However, split standards would not necessarily lead to a competitive advantage for one or the other engine type. For example, the public record for this rulemaking clearly indicates that HDDEs are already achieving the statutory CO standard. HDGEs, on the other hand, could have substantial difficulty meeting that standard by 1985, and in fact would need to utilize an oxidation catalyst-based control system in most cases. Thus, having the <u>same</u> standard for both engine types results in a large initial cost disadvantage for HDGEs. Even when the gasoline standards are relaxed to levels where catalysts would not be necessary, but the diesel standards remain at the statutory level, the average incremental diesel engine cost would be less than the average incremental gasoline engine cost. In this case, the promulgation of split standards would clearly promote equity for the two engine types, while retaining the same standards results in a definite cost advantage for diesels. Therefore, EPA has determined that while the possibility of creating a competitive advantage due to split standards does exist, each individual instance must be carefully analyzed on its own merits to determine if such an advantage would be created.

EPA disagrees with the claim by GM, Ford, and Chrysler that the CAA disallows the setting of separate standards for HDGEs and HDDEs. While GM and Ford raise valid points of legislative history, it is important to realize that no action was ever taken to write these Committees' intents into the CAA, nor is there any indication that such intents were endorsed by the conference committee or the Congress as a whole in establishing the final 1977 amendments. Moreover, although the legislative history cited by both GM and Ford may indicate the House Committee's intent as to how EPA should exercise its discretion, the quotation is more suggestive than mandatory. The actual wording of the CAA, on the other hand, confers broad authority on EPA in this area. According to §202(a)(3)(A)(iv), the Administrator "...may base such classes or categories on gross vehicle weight, horsepower or <u>such other factors as may be appropriate</u>" (emphasis added).

The CAA obviously established the same statutory standard for both engine classes in §202(a)(3)(A)(ii), as GM pointed out. EPA continues to move toward that goal. However, in the provisions for temporary revised standards the CAA calls for technology-based interim standards. The technology, cost, leadtime, and fuel economy considerations involved in establishing such interim standards are all fundamentally engine-type dependent. Thus, it would seem that consideration of basic engine type is clearly an "appropriate factor" under the §202(a)(3)(A)(iv) definition, and that the CAA allows the Agency to establish split standards for HDDEs and HDGEs.

It should also be remembered that distinctive, technology-related standards for HDEs are not foreign to EPA's application of the CAA. Smoke emission standards currently apply to HDDEs, but not HDGEs. EPA has also proposed particulate emission standards to be applicable to diesel engines only, and has recently established evaporative emissions standards for HDGEs only. In none of these cases has any question been raised as to the appropriateness of split standards.

Both GM and Ford claimed that statements made by EPA in the LDT/HDE NOx ANPRM (46 FR 5845), which indicated the Agency's intent to propose a single revised NOx standard for both gasoline and diesel engines, must apply to this rulemaking as well. EPA disagrees with the commenters' claim. Those statements did not reflect a final Agency policy statement, but indicated a preliminary EPA position on the single vs. separate standards issue for HDE NOx, published for public comment in an ANPRM. That position was clearly subject to change as is Agency policy in general. This is especially true when circumstances and conditions change or when new regulatory situations arise. It is in this light that EPA has raised the issue of split standards for HDE HC and CO.

The possible application of split standards for HC and CO likewise should not be taken as precedent setting for HDE NOx. EPA analysis here indicates the Agency's authority to set such standards, and will momentarily discuss further considerations in any decision to use this authority. All of this analysis should make it clear that the approach for NOx standards could be different than the approach for HC and CO standards. For example, in the range of standards now being considered for HDE NOx, gasoline and diesel engine control costs are similar for the same standards. However, if a single set of HC/CO standards were adopted, such as the statutory standards, then inequitable costs due to widely differing technology requirements could result. Therefore, a single set of HC/CO standards might be inappropriate because of significantly different costs between two engine types, while a single NOx standard might be appropriate because emission control costs are nearly the same for gasoline and diesel engines.

General Motors was concerned that the incentive for developing innovative technology could be diminished if the standards applicable to such new technology are overly stringent. When and if the Agency considers standards for new technology engines, it will need to consider this valid concern. However, this rulemaking does not involve new technology engines, and is unlikely to have an impact on the development of new technologies. Therefore, while the Agency may need to evaluate this concern in future rulemakings, the problem does not arise in this final rule.

General Motors' final concern was that if split standards were developed, then the Agency might consider as standards 90 percent reductions from uncontrolled levels for both diesel and gasoline engines. GM stated that a 90 percent reduction in HC and CO for diesels is technologically infeasible. We conclude that GM's concern is ill-founded. As already stated above, the CAA obviously established the same statutory standards for both engine classes. EPA recognizes that diesel engines are inherently low emitters of HC and CO. EPA always has and will continue to analyze the technical feasibility of standards it promulgates.

The Engine Manufacturers Association suggested that the Agency propose a rulemaking on split standards. EPA concludes that since the Agency has requested comment on this issue both at the public hearing and in a published notice (47 FR 12366), and has received substantial comment, the requirements for establishing the Agency's position have been met. Thus, a separate rulemaking on split standards is not necessary.

Conclusion

EPA concludes that the CAA gives the Administrator authority under §202(a)(3)(A)(iv) and §202(a)(3)(C)(i) to set split standards. Furthermore, while there may be in some cases potential problems concerning competitive advantage and innovative technology incentives, each situation must be analyzed on its own merits. Therefore, split standards will be employed where necessary and appropriate, as is the case for this rulemaking.

7. Issue: Cold Start Requirements

Summary of the Issue

The heavy-duty engine (HDE) emission test procedures applicable to 1984 and later model year HDEs require that the test begin with a cold engine, and that a 1/7 weighting be applied to the emissions measured from the cold start segment of the test. Commenters questioned the need for the cold start requirement and disagreed with the cold start weighting.

Summary of the Comments

Commenters stated that the cold start requirement for diesel engines is not necessary because the weighted emission results (1/7 of cold start and 6/7 of hot start) are almost identical to the emission results obtained from the hot start portion of the test. Comparisons of the results obtained either by individual manufacturers or from EMA/EPA round-robin tests were expressed in several forms to support the position that the cold start requirement is not necessary.

For diesel engines, the comparisons were expressed in terms of a correlation coefficient. Daimler-Benz expressed their results as a range of differences between the ratio of cold start results to hot start results. The Engine Manufacturers Association (EMA) analyzed the data to determine the predicted "error" at the 95 percent confidence level in the emission results if based upon only hot start test data. The projected errors were: 0.1 grams per brake horsepower-hour (g/BHP-hr) NOx, 0.08 g/BHP-hr HC, and 0.05 g/BHP-hr particulate. These errors were also noted to be less than the variations seen from one test to the next.

For gasoline engines, commenters made the comparison in terms of the ratio of hot start emissions to weighted emissions, and expressed the result as a percentage. All of the comments indicated that the cold start test had very little, if any, effect on total test results.

The reasons given by the commenters for the good agreement between hot test results and the weighted results (for both diesel and gasoline) were: 1) engine warm-up requires about five minutes, and this warm-up period occurs in the very first segment of the cold start portion of the test, 2) the exhaust mass flow rates are low during the first segments of both the cold start and hot start portions of the test, while being high and essentially equal during the third segment of both portions of the test, 3) the high exhaust gas mass flow rate of segment three tends to overpower the effects of the other segments, and 4) application of a weighting factor to the cold start portion of the test further reduces the overall effect of these emissions on the final weighted test result. Commenters agreed that HDEs are started from cold, but argued for the elimination of the cold start requirement because of its minimal impact on total test emissions.

Commenters stated that significant cost savings would be realized by manufacturers through removal of the cold start requirement. The cost savings would accrue from: 1) better utilization of test facilities, 2) fewer test cells would have to be built because of better test cell utilization, 3) reduction in the number of lost tests (instrumentation and hook-up of equipment cannot be checked prior to the start of a cold test), and 4) reduction in development and certification leadtimes. Forced cooldown does not solve the facility problem because it still requires four to five hours to perform and still results in only one test per day. Cummins provided an estimate of the costs attributable to lost tests associated with the cold start requirement. The estimate was between $160,000 and $200,000 per year.

Commenters also disagreed with the weighting applied by EPA to the cold start portion of the test. Commenters stated that the CAPE-21 data showed that 1.6 percent of total vehicle operation was with a cold engine. Commenters stated that if EPA believes that test engines must be cold started, it was recommended that the weighting for the cold start portion of the test be changed. Ford recommended that the weighting for the cold start portion of the test be 1/16 instead of 1/7. The 1/16 weighting was developed by making each of the four segments of the cold start portion of the test equal to 1.6 percent of the total with the resulting cold start portion equal to 6.4 percent or 1/16 of the total. As part of this issue, commenters also disagreed with the EPA methodology for determining the number of truck trips per day. Commenters stated that, on the basis of the CAPE-21 data, the average truck was used for nine trips per day (based upon mean values) and that it was an error to use the median number of truck trips per day, as EPA had done, as the basis for the cold start weighting.

In final comments submitted by May 6, 1983, EMA also presented a detailed reanalysis of the cold start weighting factors. EMA used mean values for calculating total operating time per day per CAPE-21 truck (EPA used median values), and alternately, used median values for operating time, but increased all median values to the extent necessary for median total accountable time to equal an 8-hour day. Using either method, EMA derived and recommended a cold cycle weighting factor of .03. (By deriving total operating time per day per truck, by assuming a single cold start per day, and by knowing reasonably well the warm-up time for a typical engine, the percentage of time an engine spends "cold" per day is easily calculated.) EMA recommended that EPA adopt the .03 weighting. Furthermore, considering the relative stringency of the HC standard, EMA argued that the entire cold start cycle be abandoned as unnecessary. "However, if EPA wishes to retain a check on new technical developments as they affect cold starting, then EPA should permit a much reduced cold start measurement effort. For example, EPA could adopt a method similar to the CO emission measurement waiver...."

Analysis of the Comments

Cold Start Requirement for Diesel Engines

Diesel engines designed to meet existing emission standards show good agreement between the hot start and the composite test results, as measured by the ratio of hot start results to composite test results.

For most current technology diesel engines, EPA agrees that there is little difference between the hot start segment result and the composite result. Comments submitted by EMA and Cummins substantiate this fact. For many diesel engines, EPA cannot find fault with the argument that the cold start cycle has a marginal effect on total test results. EPA also recognizes the economic implications of 100 percent cold start testing. A significant percentage of dynamometer space is idled while engines are cooling (thereby increasing the number of dynamometers necessary for a given program, and thus increasing the facility expenditures). Additional cost is involved both in running the extra cold cycle and in procuring equipment necessary for forced engine cooling. EPA concurs that it makes no sense to impose a costly cold start testing burden if no benefits are to be achieved.

On the other hand, EPA is reluctant to remove the cold start requirement entirely for heavy-duty diesel engines (HDDEs). Some engines do show a difference between cold and hot emissions. Furthermore, HDDEs have yet to experience the most technologically difficult emission reductions (i.e., NOx and particulate). These will probably require the use of new and elaborate emission control techniques. It is EPA's experience with other internal combustion engines that, as emission standards become more stringent, unique operational modes such as cold starts take on greater significance and contribute more to the total test result. This may also be observed in future HDDEs. If so, a cold start test will become increasingly necessary. However, if the cold start requirements are abandoned today, they will be administratively difficult to reimpose in the future when they may be most needed.

An alternative to the "all-or-nothing" approach has been suggested by EMA. EMA recommends that an approach be taken similar to that taken with the measurement of CO emissions from HDDEs. HDDEs emit CO well below the level of the applicable CO standards. In recognition of both this and the expenses incurred in measuring CO, EPA waived the requirement for HDDE manufacturers to report CO emission levels. This waiver was made with the explicit condition that CO emission standards still apply, and that the risk of non-compliance still rests with the manufacturer.

Such an approach is appropriate for heavy-duty diesel cold start test results. Under this approach, EPA could allow submission of only hot start data in certification applications. The official test procedure, however, will remain a cold/hot test which will still be run for all confirmatory tests. The manufacturer would then accept any jeopardy arising from potential differences in test results. As always, a manufacturer may run whatever tests deemed necessary for in-house development testing. In this way, the cold start testing burden is minimized if a manufacturer is confident that a cold start is actually insignificant. In fact, marginally greater cold start emissions may be adequately simulated much the same way that expected in-use deterioration is: by downwardly adjusting hot start emission target levels. On the other hand, if a cold start is indeed significant for a given engine, these are the very engines on which cold start testing should be performed. Since the jeopardy of non-compliance still would rest with the manufacturer, EPA has sufficient assurance that necessary testing will take place.

Cold Start Requirement for Gasoline Engines

EPA has reviewed the emission data collected during its baseline testing programs. For uncontrolled engines, about 11 percent of total hydrocarbons measured over the transient test were attributable to the cold start segment. In later testing (the 1979 current technology baseline), the cold start contribution to composite test results ranged from 4.5 to 37.7 percent for HC, and from 1.5 to 10.2 percent for CO. As total emissions decreased, the percentage contribution of the cold start was observed to increase. Finally, for emission tests on engines equipped with catalysts, the cold start test dominates total HC emissions, and becomes a greater percentage of total CO emissions. This finding is nothing new or surprising: all testing on catalyst-equipped vehicles substantiate the importance of the cold start on the emissions of gasoline-fueled vehicles.

The implications of this data are clear. For current and future technology heavy-duty gasoline-fueled engines (HDGEs), the cold start is not only significant for HC and CO emissions, in the future it will become the dominant source of HC emissions. This conclusion was challenged to some extent by the gasoline engine industry. Emissions data from prototype 1985 engines were submitted which indicated that the cold start had very little effect on total emissions. However, these data were collected on engines with cold start emission control; without a cold start test, such control would not be necessary and cold engine emissions would again be significant.

EPA continues to believe that the cold start test is critical for accurate characterization of HDGE emissions, and should be retained.

Cold Start Weighting

In the "Summary and Analysis of Comments to the NPRM: 1983 and Later Model Year Heavy-Duty Engines, Proposed Gaseous Emission Regulations" (December 1979), EPA showed that the average percentage cold operation observed in the CAPE-21 study for gasoline trucks was 5.5 percent and that for diesel trucks it was 4.3 percent. These values were developed from the median number of trips per day per truck (4.43 for diesels and 9.06 for gasoline), and the median time of each trip (26 minutes for diesels and 10 minutes for gasoline). EPA also assigned a cold operating period of five minutes only to the first trip of the day, thereby treating all other trips as hot start trips. (In practice, some of these other trips will be started from temperatures colder than fully warmed-up because of engine cooling between trips.) The Summary and Analysis of Comments document went on to determine the percentage of cold operation during the cold start portion of the test and compared these results to the CAPE-21 data. During the cold start segment of the test, cold operation was calculated to be 3.7 percent for gasoline engines and 3.6 percent for diesel engines. Based upon the comparison of the test cycle's percentage of time in cold operation to that of the CAPE-21 data, EPA concluded that the test slightly understated the on-road condition.

In recent comments, both EMA and the gasoline engine manufacturers have disputed the derivation and values of EPA's weighting factors. Ford recommended a cold start weighting of 1/16 (.0625); EMA recommended a weighting of .03. The differences between EPA's and the industry's weighting factors are based upon two differences in assumptions:

1. EPA used median CAPE-21 values as the necessary parameters to calculate a cold start weighting, while the industry used mean values; and

2. The industry assumed that the entire cold start test cycle was "cold", (i.e., the engine did not warm-up) and continued to produce cold emissions during the entire 20-minute cycle.

EPA believes that its assumption in 1. above is more reasonable than the industry's; EPA also believes that the industry's assumption in 2. above is incorrect.

The truck population sampled in CAPE-21 was highly diverse. Any given parameter, especially those used to determine the cold start weighting, was decidedly <u>non-normal</u> (see Figure 1.) In non-normal distributions, medians are far better indicators of central tendency (i.e., the "typical" truck). Means tend to be skewed by a small number of very different parameters. For this reason EPA's use of medians represents a more reasonable method of determining "typical" values.

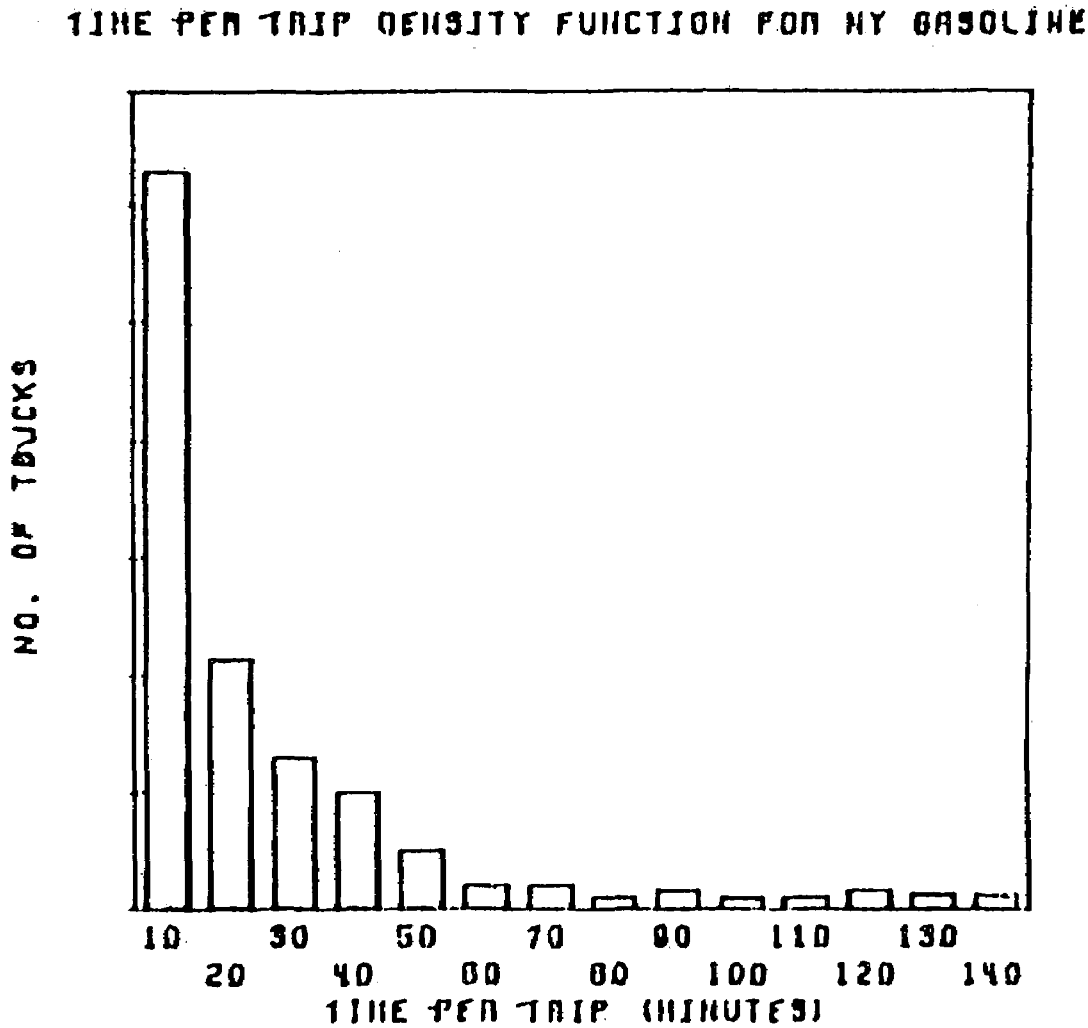
Also, to hold that the engine remains cold during the entire cold start cycle is incorrect. Oil temperature data gathered by EPA, and EMA's own test data indicate that the engine reaches a warmed-up state somewhere between 5 and 10 minutes into the test. In other words, emissions during the remaining portion of the cold test cycle are no different than those of the warmed-up hot cycle, and for this period of time the weighting factor value is irrelevant. If we assume that the first five minutes, or 300 seconds, of the 1,199 second diesel test cycle are actually cold, then 300/1,199 or 25.0 percent of the cycle is cold. Since the entire cold cycle is then weighted by 1/7, the cold engine emissions are actually weighted by 1/7 x .250, or 3.6 percent of the total test result. If we continue to make the assumption that the engine warms-up in the first five minutes of operation, as did EPA when it derived its original weighting factors, we find that the percentage of cold operation in the test cycles are 3.6 percent for diesels and 3.7 percent for gasoline-fueled engines. If a 5-minute warm-up is similarly assumed for the first trip of the day from the CAPE-21 data, the actual percentages of on-road time spent with a "cold" engine are 5.5 percent for gasoline-fueled engines and 4.3 percent for diesels.

In summary, EPA cannot agree that the present cold start weightings are unrepresentatively high; if anything, they might understate those observed in CAPE-21.

<u>Conclusions</u>

1. The cold start requirement for both gasoline and diesel-fueled HDEs will be retained.

Figure 1


TIME PER TRIP DENSITY FUNCTION FOR NY GASOLINE
NO. OF TRUCKS
10
20
30
40
50
60
70
80
90
100
110
120
130
140
TIME PER TRIP (MINUTES)

2. The present 1/7 cold start weighting will be retained

3. Diesel engine manufacturers may report only hot start data when making application for certification. For confirmatory, SEA and recall testing, however, EPA will retain the option of using either the hot start or cold start tests; the cold start test will be retained as the official test.

8. Issue: Diesel Engine CO Measurement

Summary of the Issue

Measurement of CO emissions is currently required for all regulated vehicles and engines, including HDDEs, during both certification and SEA testing. All of the comments received on this issue were in agreement: the CO emissions of HDDEs are so far below all applicable standards, current and proposed, that any requirements for HDDE CO measurements are unnecessary and should be deleted.

Summary of the Comments

All of the commenters referred to the very low CO emissions of HDDEs, exemplified by the mean CO level of 3.27 g/BHP-hr for all 1981 model year certified HDDEs, less than one-sixth of the 25 g/BHP-hr standard applicable under the 13-mode test. The cost savings to the manufacturers resulting from deletion of the diesel CO test requirements are estimated at $20,000 annually per manufacturer by Mack and EMA. Cummins estimated that deletion of these requirements would result in a 25 percent annual reduction in their equipment, maintenance, and storage costs. Several manufacturers noted that valuable laboratory test time would also be made available if the CO test requirements are deleted for HDDEs.

The manufacturers also indicated that they feel that the deletion of diesel CO test requirements should be completed as soon as possible, rather than awaiting the final implementation of the transient test procedure as was originally proposed.

All of the manufacturers commenting noted that since HDDE CO emissions are inherently so low, they had no substantive comment on the proposed revisions to the level of the standard.

Analysis of the Comments

As was noted in several of the comments, EPA has already agreed to delete all certification and SEA CO measurement requirements for HDDEs. This action has been implemented through technical amendments to the regulations. Revision of the diesel CO measurement requirements took effect as soon as those amendments were issued (47 FR 49802, November 2, 1982). This action is appropriate as a regulatory relief measure, and is not expected to have any negative air quality impact.

Conclusion

No further action is necessary, since the requested changes have been made.

9. Issue: Parameter Adjustment

Summary of the Issue

The original FRM (45 FR 4136, January 21, 1980) contained regulations describing the parameters subject to adjustment during certification and SEA testing. Few comments were received on this issue. The only significant concern of the manufacturers appeared to be the possibility of manual choke settings being subject to the parameter-adjustment regulations.

Summary of the Comments

Two of the three manufacturers commenting indicated concern over the possibility that, under a strict interpretation of the current rules, the Administrator could require manual chokes to be adjusted over the full range of their authority during certification and SEA testing. The operation of a manual choke should not be confused with tampering, one manufacturer noted. A slight revision to the wording of §86.084-22(e)(1)(i) was suggested by the second manufacturer as a means of removing any ambiguity concerning the applicability of the parameter-adjustment regulations to manual chokes.

One manufacturer noted that EPA had previously determined that the parameter-adjustment regulations do not apply to idle speed or to ignition spark timing. The comment suggested that references to these two parameters be deleted from §86.084-22(e)(1)(i) in accordance with this determination.

Analysis of the Comments

EPA agrees that the manual choke should not be considered a parameter in the context of the parameter-adjustment provisions. While a manual choke is clearly an adjustable parameter, its operation is governed by Subpart N test procedure provisions and therefore manual chokes were not included in the list of adjustable parameters of §86.084-22(e)(1)(i). In fact, to add manual chokes to that list would require public notice and comment plus a minimum of two years of leadtime. Inclusion of choke operation under Subpart N is based upon viewing a manual choke as an operating control (as are, for example, shift points on a manual transmission) rather than a parameter subject to the parameter-adjustment provisions. EPA believes this is the appropriate approach.

EPA also believes that to subject manual chokes to the parameter adjustment provisions would in effect prohibit their use. At this time, EPA has no evidence of systematic improper use of chokes on HDEs to justify such an action. In addition, it is likely that as future emission reductions are required, manual chokes will gradually be phased out of use by manufacturers (similar to what has already happened for LDVs).

Concerning the request to delete idle speed and ignition spark timing from the regulations, the Agency has already taken the necessary steps to implement its findings that these two parameters need not be adjusted. Manufacturers were notified by two letters that these parameters would not be subject to adjustment under the parameter-adjustment requirements.[1,2] Since the list of parameters in §86.084-22(e)(1)(i) is discretionary rather than mandatory, EPA sees no need to make changes to the regulations.

Conclusions

In order to eliminate any possible ambiguity over the adjustment of manual choke settings during certification and SEA testing, EPA has decided to add a new paragraph §86.085-22(e)(1)(iv) to read, "Manual chokes will not be considered an adjustable parameter for HDEs subject to adjustment under this paragraph." In addition, EPA will revise paragraph §86.085-22(e)(1)(i) to read, "Except as noted in §86.085-22(e)(1)(iv), the Administrator may determine...." EPA has also decided not to change the references to idle speed and ignition spark timing in §86.085-22(e)(1)(i).

References

1. EPA Memorandum From Michael P. Walsh, OMSAPC, To Light-Duty Vehicle and Heavy-Duty Engine Manufacturers, August 22, 1980.

2. Deletion of Spark Timing Parameter Adjustment Requirement, EPA Memorandum From Michael P. Walsh, OMSAPC, To Light-Duty Vehicle, Light-Duty Truck and Heavy-Duty Engine Manufacturers, October 28, 1980.

10. Issue: Potential Impacts on Specific Manufacturers

Summary of the Issue

Several commenters claimed that even though EPA has proposed revisions to many of the 1984 HDE requirements, these provisions may still cause substantial harm to the industry. The impact of these revised regulations on the HDGE manufacturers' future product offerings and financial situations, based on the comments received, are discussed in this section. The impact of the rule on Chrysler is considered separately from the impact on the other manufacturers.

Summary of the Comments

Chrysler Corporation

In its initial submission to the docket, Chrysler indicated that it was planning to withdraw from the HDGE market in the near future. At that time, Chrysler stated that the potential profitability of the HDGE market in the 1980's was thought to be insufficient to justify directing scarce capital resources into the development of the necessary transient test facilities and the development of HDGE emission control systems capable of meeting the revised standards. More recent comments received from Chrysler indicate that, based on the improving financial condition of the corporation and a reassessment of the profit potential of manufacturing HDGEs, it is now planning to remain in the market.

However, these recent comments also include several reservations that Chrysler continues to have concerning the regulatory requirements. Primary among these is the claimed inability of Chrysler to develop transient test capabilities for at least three years. For this reason, Chrysler suggests the creation of a "small-volume manufacturer" category, defined as any HDGE manufacturer building only engines that are derived from passenger car engines; and that such "small-volume manufacturers" be allowed to certify under the steady-state procedure for up to three more years.

In its comments, Chrysler preliminarily rejected two additional options (beside the extension of the steady-state test option) that are available for compliance with these regulations. First, vehicles up to 10,000 lbs. GVWR and equipped with HDGEs may now be certified, at the manufacturer's discretion, to LDT emission standards under the light-duty chassis test procedure (FTP). During the public hearings, EPA asked Chrysler representatives whether an increase in the 10,000 lbs. maximum, for example to 11,000 lbs., would make it easier for Chrysler to take advantage of this certification option. Its answer was no; Chrysler does not currently plan to certify any of its 1984 vehicles in the 8,500-10,000 lbs. GVWR range as LDTs, and in its opinion, increasing the upper bound of this range offers no meaningful relief. The second option, to use outside engineering services to conduct transient testing and certification, was rejected by Chrysler on the basis of excessive cost and insufficient leadtime remaining before scheduled compliance.

In response to EPA's inquiry as to what would constitute an appropriate level for steady-state test emission standards, in the event that this procedure is allowed as an option to the transient test, Chrysler maintained that the present standards cannot be made more stringent if engines without catalysts are to meet them. It went on to state that with additional development it may be possible for Chrysler to meet the current steady-state standards without catalysts, but that the present standards appear to be at the limit of non-catalyst emission control technology. Chrysler does not feel that the 1984 California emission standards (0.5 HC, 25 CO, 4.5 HC+NOx) can be met on a steady-state test without catalysts.

Chrysler also noted that it is the only manufacturer now using catalysts on its HDGEs (5.2L and 5.9L engine families), a decision that was made on the grounds that development costs and manufacturing complexity would be minimized. Chrysler maintains that it is confident that "real-world" emissions from these engines are low; thus, it claims it is ironic that the proposed revisions to these rules, intended to make it possible to certify HDGEs without catalysts, may result in Chrysler being forced to withdraw from the market.

Other Commenters

In addition to Chrysler, comments on the potential impact of these rules were also submitted by IHC, American Motors Corporation (AMC), and the National Association of Van Pool Operators (NAVPO). These comments are summarized below.

International Harvester Corporation has already made public its intention to abandon the HDGE market when the revised HDGE regulations take effect, after which it will only manufacture HDDEs. This decision was based primarily on the rapid and continuing decline in the demand for HDGEs, although IHC noted that the implementation of a transient test procedure was a contributing factor. If these regulations were to take effect for the 1984 model year, as originally planned, IHC would leave the HDGE market at the end of the 1983 model year. Therefore, IHC has requested that the effective date of these regulations be delayed until the 1985 model year, thereby allowing it to plan a more orderly withdrawal from the HDGE market.

American Motors Corporation noted that it has not certified any HDGEs in recent years; however, Renault is planning the introduction of both HDGEs and HDDEs to the medium-duty truck market over the next few years. AMC does not have, or plan to acquire, transient test capabilities, but it will be responsible for the certification of the Renault HDGEs when they are introduced. Therefore it intends to contract for this work, although it expressed some concern over the availability of and competition for independent laboratory time. Given this background information, AMC requested that the implementation of the 1984 HD standards and test procedures be delayed until 1985, and that EPA "...consider waivers for low-volume (less than 10,000 units) domestic manufacturers."

The National Association of Van Pool Operators' comments were concerned entirely with the potential impact of these rules on the manufacturers' product offerings. They expressed concern over the possibility that the 12- to 15-passenger vans that are most economical for van-pooling programs may no longer be available if the emissions regulations applicable to them are strengthened. A later conversation between EPA and a representative of NAVPO revealed that their concern is focused on the larger passenger vans manufactured by the Chrysler Corporation.

Analysis of the Comments

Chrysler Corporation

As noted in the summary of Chrysler's comments, Chrysler has decided to remain in the HDGE market. This decision must have been based on the improving financial condition of the company, as well as the belief that the profit potential of HDGE manufacturing in the 1980's will be sufficient to justify the necessary capital expenditures. The significant stabilization of gasoline prices late in 1981 and in 1982, and the 1-year delay in the effective date of these regulations, may also have contributed to Chrysler's reevaluation of its decision.

EPA has estimated that the capital costs to Chrysler for transient test facilities, plus additional engineering costs for facilities checkout and engine development, would total approximately $2.9 million in 1982 dollars. Considering that Chrysler, in its first and second quarterly reports, showed profits of $256.8 million for the first six months of 1982, it appears that it currently has liquid assets adequate to underwrite this investment. While recognizing that the firm currently has major debt servicing obligations, and that therefore not all of these recent profits are available for capital expenditures, EPA can only conclude that Chrysler is capable of making these investments, given the decision by management to do so.

Chrysler maintains that it will be unable to develop in-house transient test capability for three years. It has preliminarily rejected the options of contracting with independent laboratories for the development and testing required during the next three years, and of certifying its HDGE vehicles under 10,000 lbs. GVWR to LDT emission standards. Claiming that both of these options are unacceptable, it requests that a "small-volume" category of HDGE manufacturers, defined so as to include Chrysler, be allowed to certify HDGEs under the steady-state test for the next three years. The implication is that Chrysler may not remain in the HDGE market unless such an exemption is granted.

Chrysler's position on whether to continue to compete in the HDGE market is primarily a business decision. The 1984 HDGE emission regulations have been discussed in the public forum for more than four years, and should have been taken into account in any earlier decisions by Chrysler regarding its HDGE manufacturing operations. Other affected manufacturers have made the capital investments necessitated by these rules (Ford, GM), or have determined that it is more economical for the work to be performed under contract (AMC), or have decided that the profit potential of the HDGE market is insufficient to justify further capital expenditures in this area (IHC). These decisions have been based on business considerations, as Chrysler's eventual decision should be. EPA notes that it appears that Chrysler could now afford to pursue either of the options discussed above, which it has preliminarily rejected, and thus that it has three approaches to meeting the requirements of these rules available to it.

In its comments, Chrysler also noted it has elected to equip two of its three current HDGE families (5.2L and 5.9L) with catalysts "...in order to minimize development costs and manufacturing complexity." While it might be ironic for the only HDGEs currently equipped with catalytic emission controls to be forced from the market by rules designed to negate the necessity of catalysts, EPA does not feel that this will be the case. Since production and sales of these catalyst-equipped engines has continued while other HDGE manufacturers did not use catalysts, the cost disadvantage resulting from catalyst use must be relatively small. Additional development work, aimed at improving the emission characteristics of Chrysler's

HDGEs, will have to be conducted if Chrysler really wishes to remain in the market.

Since Chrysler has decided that its position in the HDGE market warrants the decision to stay in that market, it must be willing to commit the necessary resources to the development of transient test facilities and improvement of its HDGE line. EPA cannot justify granting what would amount to a 3-year delay in the effective date of these regulations to some, but not all, HDGE manufacturers. This is particularly true since other firms, as noted above, have undertaken the investments required by these regulations, and since the financial condition of Chrysler has now improved. In addition, the 1-year delay in the effective date of these rules provides Chrysler (and the other manufacturers) additional time for compliance.

Other Comments

The major interest of IHC is that the effective date of these HDGE regulations be delayed for an additional year, so that its planned withdrawal from the market may proceed in an orderly fashion. Due primarily to leadtime considerations, this is being done. As was indicated by IHC, its decision to withdraw from the HDGE market was made more on the basis of financial considerations than on the effect of these regulations.

The position of AMC with respect to the certification of HDGEs manufactured by Renault is recognized as the basis for its decision to contract with independent laboratories for this work. As noted previously, the effective date of these standards is being delayed until the 1985 model year, as desired by IHC and AMC. However, AMC's request that EPA consider waivers for "low-volume domestic manufacturers" is unclear. Historically, EPA has rejected requests for waivers from the use of applicable test procedures, and EPA sees no other suitable way to determine compliance. On the other hand, waivers from durability testing requirements and certain other certification procedures have been granted in the past and would be available in this context. These waivers are available to manufacturers whose combined U.S. sales of LDVs, LDTs, and HDEs are under 10,000 units.

The National Association of Van Pool Operators' concerns about the availability of 12- to 15-passenger vans under the new regulations appear to be groundless. The only manufacturer of such vehicles that was considering dropping out of the HDGE market as a result of these regulations (Chrysler) has decided to remain, as noted above. Aside from that decision, none of Chrysler's passenger vans are currently certified as HDGEs--all are less than 8,500 lbs. GVWR--and so these rules should have no effect on the continued production of these vehicles.

Conclusions

For the reasons discussed in the preceding analysis, EPA does not feel that allowing Chrysler (or any of the other manufacturers) to use the steady-state test rather than the transient test for the next three years can be justified. Therefore, EPA rejects the "small-volume manufacturer" exemptions proposed by Chrysler and AMC.

The concerns of IHC about being able to plan its withdrawal from the HDGE market in an orderly manner, and of AMC about having adequate time to plan and contract with independent laboratories, are addressed by the delay in the effective date of these rules until the 1985 model year.

The concerns expressed by NAVPO are unfounded. EPA has decided not to make further changes in these rules based on the comments received from NAVPO.

11. Issue: Transient Test Procedure - Technical Details

Summary of the Issue

On June 17, 1981, EPA solicited manufacturers for information regarding operational aspects of running the transient test (46 FR 31677). On January 13, 1982, EPA reopened for comment all aspects of the transient test as part of the proposed revisions to the 1984 requirements.

In their comments, the heavy-duty industry recommended that large numbers of technical amendments be made to the transient test procedure. These amendments were justified as necessary on the basis of technical merit and cost reduction.

EPA has also recognized the need to modify specific sections of the transient test. This has become apparent as more actual testing exerience was gained by both EPA and the industry.

Summary and Analysis of the Comments

Each comment and technical amendment is not significant enough to justify devoting an individual section to its discussion. Collectively, the amendments represent a clarified, streamlined, and technically improved test procedure.

The format for this discussion will be a section-by-section breakdown of the transient test procedure (Subpart N). Specific modifications will be noted, as will the rationale for the changes. Note that some technical amendments were requested by industry, while others are being made by EPA's initiative.

Also note that some technical amendments were necessary in the heavy-duty diesel engine smoke test procedure (Subpart I) and the heavy-duty gasoline engine and light-duty gasoline truck idle test procedure (Subpart P). A list of these changes will follow those of the transient test procedure.

A. Subpart N - Transient Test Procedures for 1984 and Later Model Year Heavy-Duty Gasoline and Diesel Engines

Overview of Technical Amendments

Large numbers of technical amendments are being made to the transient test procedure.

In general, amendments have been made to correct errors and omissions, to clarify requirements, to minimize prior approvals by the Administrator for inconsequential deviations from the existing procedures, and to reduce costs associated with running the test.

All changes except corrections of typographical errors are listed below.

Specific Technical Amendments

The following sections from 40 CFR Part 86 are being amended:

§86.1308-84(a) Torque and speed accuracies rereferenced. Eliminated need for Administrator's approval for using dynamometer currents for torque measurement.

Most accuracies within the test procedure were respecified to provide greater traceability to NBS standards. Also, several manufacturers have developed methods for using dynamometer currents as surrogates for direct torque measurements; EPA is reasonably convinced that the techniques are technically acceptable and need not have advance EPA approval.

§86.1308-84(b) Torque cycle verification equipment accuracy changed from ±3 percent to ±2 percent (to equal speed cycle accuracy).

Torque cycle accuracy was changed to be comparable to that required for speed, to correct an earlier oversight.

§86.1308-84(e) Clarification of dynamometer calibration procedures, and rereferencing of accuracies.

Existing dynamometer calibration procedures were unclear, and required procedural clarifications. No substantive technical changes have been made. Again, accuracies were rereferenced to provide greater traceability to NBS standards.

§86.1308-84(f) Added specification for mass fuel flow measurement device for diesel engines.

The option for direct measurements of mass fuel flow for diesel engines was added; this addition required inclusion of an accuracy specification for the flow measurement equipment.

§86.1309-84(a)(5) — Clarified required degree of compliance with analytical system schematic.

This change represents a simple clarification of minor deviations which are allowable under the existing equipment specifications. Previously, there was some uncertainty within the industry as to what deviations would be acceptable to EPA.

§86.1309-84(b)(1) and (c)(1) — Clarified rationale and means of verifying that CVS-induced pressure variations on the exhaust system are not excessive.

Both the rationale for and the means of verifying this specification were questioned by the industry; this procedural change clarifies both the intent and the procedure itself.

§86.1309-84(b)(2) — Rereferenced CVS gas mixture temperature accuracy from the temperature at the start of the test to the average operating temperature during the test.

This is a minor change, simply changing the reference temperature against which the temperature excursions of the dilute exhaust are measured. Because the temperatures during a test never go below the temperature at the start of the test, the previous specification was actually twice as stringent as needed be.

§86.1309-84(c) — Clarified sensor accuracy requirements to include the signal transmission and readout equipment.

This amendment corrects a previous omission, and more correctly includes all sources of equipment error within required accuracy specifications.

§86.1309-84(c)(2) — Relaxed temperature measurement system response time from 0.100 to 1.50 seconds; eliminated response time requirement for CVS equipment with heat exchange.

This response time relaxation reflects the uncertain commercial availability of fast-responding temperature sensors for CFV-CVSs. CVSs with heat exchangers do not require temperature sensors with fast response characteristics, and are thus exempted from the response time specification.

§86.1310-84(a) Permitted measurement of mass fuel consumption in lieu of CO_2 exhaust measurement. Clarified general sampling system requirements.

This option, requested by EMA, permits a manufacturer to measure mass fuel consumption in lieu of CO_2 exhaust concentration. Either of the two measurements is acceptable for calculation of exhaust emissions, however, the equipment for measuring mass fuel flow is much less expensive to procure and maintain. In addition, general sampling system requirements were clarified where ambiguous or misinterpreted by the industry.

§86.1310-84(a)(5) Clarified required degree of compliance with analytical system schematics.

The industry requested clarification of the degree of compliance which EPA requires for components of the exhaust analytical system. Specifically, minor deviations in equipment components are permitted; many of these deviations are indicative of the different equipment a manufacturer may use.

§86.1310-84(b)(2)(iii) Rereferenced CVS gas mixture temperature accuracy from the temperature at the start of the test to the average operating temperature during the test.

This is a minor change, simply changing the reference temperature against which the temperature excursions of the dilute exhaust are measured. Because the temperatures during a test never go below the temperature at the start of the test, the previous specification was actually twice as stringent as needed be.

§86.1310-84(a)(3) Removed requirements for Administrator approval for use of continuous sampling systems.

Many diesel engine manufacturers are already using continuous sampling systems, the viability of which have been demonstrated in EPA/EMA correlation programs. The test procedure already contains generalized specifications for continuous sampling systems; EPA feels that these are sufficient to guarantee correlatable test results, without the unnecessary step of requiring advance EPA approval.

§86.1310-84(b)(3)(i) Revised HC "overflow" technique to be an optional calibration, but mandatory zero and span check of the sampling system.

EPA's earlier requirement that the HC emissions analyzer be calibrated through the overflow system has been changed; calibration will now take place at the analyzer ports, with zero and span checks still being made through the overflow system. EPA believes that the revision is more technically correct, consistent with light-duty practice, and still adequately permits the identification of potential hang-up problems.

§86.1310-84(b)(3)(ii) Included provision for use of a single sample line.

The industry requested this change, and suggested wording which allowed only the use of a single sample pump. EPA's earlier requirement that different analyzers use different sample lines was based upon concern about potential errors arising from pressure fluctuations induced by more than one sample pump. The revised wording as suggested by the industry satisfies EPA's concern, and has been incorporated into the test procedure.

§86-1310-84(b)(3)(iii) Reduced HC "overflow" gas flow rate to at least 105 percent.

The earlier version of the test procedure required excessive overflow gas flow rates; the industry argued that this was wasteful of calibration gases, and that any quantity of gas greater than 100 percent total flow was sufficient. EPA concurs with this observation.

§86.1310-84(b)(3)(v)(A) Eliminated requirement that gaseous HC probe point only upstream.

The industry requested this modification because probes pointing upstream are susceptible to contamination by large particles (for example, collected particulate matter intermittently shaken off the walls of the exhaust system, engine parts, etc.). Exhaust gas flow is sufficiently isokinetic to allow the probe to point in any direction without impacting the accuracy of the measurement of gas concentration.

§86.1310-84(b)(3)(v)(C) Eliminated specific insulation requirement as the only means of maintaining sample probe wall temperature.

Measurement system integrity requires that the wall of the HC sample probe be maintained at a sufficiently high temperature. EPA's earlier requirement specifically dictated how that temperature was to be maintained; the revised test procedure simply requires that the temperature be maintained, and leaves the method of temperature maintenance to the discretion of the manufacturer.

§86.1310-84(b)(3)(vi) (A) and (B) — Clarified sensor accuracy requirements to include signal transmission and readout equipment.

This amendment corrects a previous omission, and more correctly includes all sources of equipment error within required accuracy specifications.

§86.1310-84(b)(3)(vi) (C) — Eliminated.

This paragraph was redundant, served no purpose to the test procedure, and was eliminated.

§86.1310-84(b)(3) (vii)(B) — Increased analyzer response time from no greater than 5.5 to no greater than 20.0 seconds.

The industry recommended this change, providing data that sampling system response times up to 20 seconds yielded equivalent emission results. EPA's original response time requirement reflected primarily a concern that the integrity of longer sample lines is more difficult to maintain, especially if heated. EPA believes, however, that sufficient requirements already exist within the test procedure for sample line heating, leak checks, and zero and span checks, in addition to the verification provided by the industry data, that increasing the sample system response time will not adversely affect test accuracy. In addition, the allowance of longer sample lines (by allowing greater system response times) gives the manufacturer much greater flexibility in modifying existing dynamometer cells for running the transient test.

§86.1310-84(b)(4) (ii)(F) — Eliminated requirement that gaseous HC probe point only upstream.

The industry requested this modification because probes pointing upstream are susceptible to contamination by large particles (for example, collected particulate matter intermittently shaken off the walls of the exhaust system, engine parts, etc.). Exhaust gas flow is sufficiently isokinetic to allow the probe to point in any direction without impacting the accuracy of the measurement of gas concentration.

§86.1310-84(b)(5)(ii)(B) Increased analyzer response time from from 5.5 to 20.0 seconds.

The industry recommended this change, providing data that sampling system response times up to 20 seconds yielded equivalent emission results. EPA's original response time requirement reflected primarily a concern that the integrity of longer sample lines is more difficult to maintain, especially if heated. EPA believes, however, that sufficient requirements already exist within the test procedure for sample line heating, leak checks, and zero and span checks, in addition to the verification provided by the industry data, that increasing the sample system response time will not adversely affect test accuracy. In addition, the allowance of longer sample lines (by allowing greater system response times) gives the manufacturer much greater flexibility in modifying existing dynamometer cells for running the transient test.

§86.1311-84(a) Clarified required degree of conformance with analytical system schematic.

The industry requested clarification of the degree of compliance which EPA requires for components of the exhaust analytical system. Specifically, minor deviations in equipment components are permitted; many of these deviations are indicative of the different equipment a manufacturer may use.

§86.1314-84(g) Allowed use of gas dividers, subject to accuracy requirements of ±1.5 percent of NBS gas standards.

Gas dividers were permitted under the old test procedure; however, accuracy specifications for their use were never provided, creating uncertainty within the industry as to what EPA actually required. This technical amendment corrects that omission by providing gas blending accuracy specifications.

§86.1316-84(c)(3) Added weekly check (not mandatory calibration) of torque feedback signals at steady-state operating conditions.

EPA believes that this procedural modification is easily performed, and reflects good engineering practice; this amendment is therefore made part of the test procedure.

§86.1318-84(b) Added required electronic check and adjustment of torque feedback signal before each test.

EPA believes that this procedural modification is easily performed, and reflects good engineering practice; this amendment is therefore made part of the test procedure.

§86.1319-84(a) — Defined flowmeter traceable to NBS as a reference standard for CVS calibration; removed need for Administrator's approval.

EPA believes that any flowmeter traceable to NBS standards which conforms to EPA's accuracy specifications is technically acceptable, and does not require advance approval by EPA for its use.

§86.1319-84(c)(2)(i) — Eliminated pump pressure tap specifications.

This part of the original test procedure was drafted verbatim from light-duty vehicle test procedures; in fact, this procedure is outdated, and is removed from the test procedure by EPA inititive.

§86.1319-84(c)(4) and (d)(3) — Changed accuracy tolerances for measurements of barometric pressure (from ±.01 inches Hg to ±.10 inches Hg), pressure head at CVS pump outlet and inlet depression at CVS pump inlet (from ±.05 inches fluid to ±.13 inches fluid), and elapsed time for test (from ±.05 seconds to ±.5 seconds). Changed air temperature measurement tolerances from ±0.5°F to ±2.0°F for PDP-CVS, and from 0.5°F to 4.0°F for CFV-CVS.

EMA submitted data and calculations which argued that relaxed calibration accuracies would not impair overall test accuracy. The requirements that these measurement accuracies be very stringent necessitated the use of very accurate but very expensive calibration equipment. EPA has reviewed EMA's calculations, and agrees that no net impact on test accuracy would be incurred. In fact, the requirement for CVS system verification using propane will still serve as an overall system check. For these reasons, EPA accepts EMA's recommendations and relaxes the tolerances.

§86.1319-84(d) — Added missing sections from light-duty CVS calibration procedure, but deleted correlation function between pump RPM and pressure differential.

During drafting of the original test procedure, several paragraphs were inadvertantly deleted; these paragraphs were substantially similar to CVS calibration procedures applicable to light-duty vehicles. These paragraphs have now been restored, with the exception of a single but unnecessary correlation function.

§86.1319-84(e)(1) Eliminated carbon monoxide as a recommended CVS verification gas.

Both EPA and industry use propane as a CVS verification gas; propane is adequate for all verification purposes. Given the adequacy of propane, and the risk to safety associated with the use of carbon monoxide, EPA no longer recommends its use.

§86.1319-84(e)(4) Corrected density of propane to 17.30 g/ft^3.

This is a minor numerical correction that makes the heavy-duty test procedure consistent with light duty.

§86.1321-84(b) Clarified requirements for HFID analyzer calibration.

This technical amendment eliminates the requirement for overflow calibration of the analyzer; the exact analyzer calibration procedure is reworded to reflect this change.

§86.1324-84(c) Permitted use of span gases for CO_2 analyzer calibration.

Span gases are "named" to a lesser degree of accuracy than calibration gases, and for this reason, calibration gases have always been used to maximize accuracy of analyzer calibrations. EMA has provided evidence that slightly less accurate calibration of the CO_2 analyzer will not affect overall test results. (CO_2 emissions measurements are used only to calculate overall dilution factor and fuel consumption.) EPA concurs with EMA's analysis, and specifically allows use of span gas for the CO_2 analyzer calibration.

§86.1327-84(d)(4) Eliminated prior approval of Administrator for inclusion of engine accessories.

Since the heavy-duty transient test is based upon normalized engine parameters, EPA is no longer concerned about parasitic effects of engine accessories. EPA therefore allows their inclusion on certification engines if the manufacturer so desires, without the requirement for advance EPA approval.

§86.1327-84(d)(5) Eliminated mandatory use of production starter.

The earlier test procedure required the use of a production starter motor at the beginning of the transient test sequence. The industry has argued for some time that this represents an unnecessary test burden. EPA no longer believes that use of a dynamometer to start the engine will significantly impact overall test results, especially since the dynamometer will be required to simulate the characteristics of a production starter.

§86.1327-84(f) Clarified and modified exhaust system requirements.

Significant clarifications to exhaust system requirements for diesel engines have been made. Specifically, use of a facility exhaust system in lieu of a chassis-type exhaust system has been required. This change has been made to provide uniformity with future exhaust system requirements which will be necessary for the measurement of particulates.

§86.1330-84(a)(1) Permitted dilution air temperatures above 86°F.

This change has been made to accommodate problems several manufacturers were having in maintaining a CVS dilution air temperatures below 86°F, especially in the summer months. Rather than force the installation of expensive air cooling equipment, EPA is eliminating the upper temperature limit of the CVS dilution air temperature. EPA does not believe that this will have any impact on test results. (Note that the dilution air temperature can readily exceed 200°F when mixed with engine exhaust.)

§86.1330-84(a)(3) Permitted test cell and engine intake air to exceed 86°F if no temperature dependent auxiliary emission control devices are used.

This modification applies almost certainly to diesel engines only, and will preclude the installation of expensive air handling and temperature conditioning equipment where such equipment is not necessary.

§86.1330-84(b) Eliminated need to control test cell, engine intake, and CVS dilution air humidity.

EPA is specifically providing the use of a humidity correction factor for both gasoline and diesel engines; for this reason, control of humidity during the test sequence is no longer necessary or required.

§86.1330-84(e) Specified inlet and exhaust restrictions for diesel engines, both naturally aspirated and turbocharged.

This technical amendment represents a clarification of earlier requirements, and was recommended by EMA. This amendment constitutes no net change in the test procedure.

§86.1330-84(f) Clarified pre-test procedures.

This amendment specifically addresses when certain operational checks of the engine and other procedural steps may be performed during the test sequence.

§86.1332-84(b) Minimum mapping speed redefined as curb idle speed.

This technical amendment eliminates the need to map the engine below idle speed. This eliminates engine and equipment stresses associated with running the engine at full load at very low speeds. No compromise in test accuracy is incurred, because very few of the engine speeds required during transient testing actually lie below idle.

§86.1332-84(d)(2)(vii) Added ± 20 rpm tolerance to 100 rpm mapping steps.

This accuracy tolerance was requested by Ford because EPA had provided no tolerance in the earlier test procedure.

§86.1332-84(d)(2)(x) and (d)(3)(viii) Added allowance for avoiding lengthy engine warm-up before mapping if the engine is already warm.

This technical amendment was requested by MVMA as a means of avoiding unnecessary warm-up required under the earlier test procedure. Since EPA's intent is merely that certain portions of the test be conducted with a warm engine, EPA is allowing that these portions of the test be conducted without warm-up, provided that certain engine temperature specifications are met.

§86.1332-84(d)(3)(iv) Eliminated mandatory 10-minute minimum time for temperature stabilization.

EPA is eliminating this unnecessary requirement on its own initiative. That the engine temperature be stabilized is the only necessary criterion; if this criterion is achieved in less than 10 minutes, there is no need to maintain warm-up for the full 10 minutes.

§86.1332-84(e)(1) Added goodness of fit criteria for cubic spline technique.

MVMA requested this amendment, so that EPA would provide an accuracy specification where the original test procedure had failed to do so.

§86.1332-84(f) Removed requirement for Administrator approval for alternate mapping techniques based upon safety or representativeness criteria.

EPA is removing the requirement that alternate mapping techniques be approved in advance by EPA, if such techniques are in the manufacturer's judgment required to maintain test safety or representativeness. General guidelines for alternate mapping techniques are provided, along with the requirement that the specific mapping technique used be reported to EPA in the manufacturer's application for certification.

§86.1332-84(g) Added conditions under which remapping need not occur.

EPA has added this clarification because several manufacturers had misinterpreted the earlier test procedure to require that an engine be mapped before each and every test. This was never EPA's intent, nor EPA's test practice.

§86.1333-84(d)(3) Clarified point deletion allowances.

This technical amendment represents a clarification of earlier requirements.

§86.1333-84(f) Added clutch allowance.

EPA has specifically added to the test procedure the allowance to use a clutch during engine testing. The earlier procedure never specifically precluded the use of a clutch; indeed, EPA recommends its use in certain circumstances. Several manufacturers, however, had misinterpreted EPA's earlier procedure, and requested that EPA specifically address the use of a clutch to alleviate any uncertainty.

§86.1333-84(g) Added required method of calculating measured rated rpm, or usage of manufacturers' specified rated rpm, whichever is greater.

EPA is initiating this technical amendment. In testing practice, EPA has found this revised methodology to be less susceptible to errors induced by unusual engine mapping curves.

§86.1335-84(c)(1)(ii) Clarified requirements for cooling water temperature.

This correction of the forced cooldown procedure permits the cooling medium to temporarily exceed the required temperature limits at the very beginning of the cooldown, as is almost always observed.

§86.1335-84(c)(2)(ii) Clarified requirements for cooling air temperature.

This correction of the forced cooldown procedure permits the cooling medium to temporarily exceed the required temperature limits at the very beginning of the cooldown, as is almost always observed.

§86.1335-84(e) Clarified means of oil temperature measurement, and when direct forced cooling of engine oil is permitted.

This amendment clarifies the method of oil temperature measurement for the forced cooldown procedure. In addition, it specifically allows the use of direct cooling of engine oil for engines with displacements greater than 500 cubic inches. This reflects the difficulty in cooling very large engines using only air and the coolant water.

§86.1336-84(a) Allowed use of dynamometer for engine starting.

The earlier test procedure required the use of a production starter motor at the beginning of the transient test sequence. The industry has argued for some time that this represents an unnecessary test burden. EPA no longer believes that use of a dynamometer to start the engine will significantly impact overall test results, especially since the dynamometer will be required to simulate the characteristics of a production starter.

§86.1336-84(b)(2) Eliminated need for approval by Administrator of longer cranking times.

EPA is eliminating the need for prior Administrator approval for engine cranking times which are longer than nominal, but nevertheless typical of the engine.

§86.1336-84(b)(3) and (4) Eliminated need to report malfunctions during engine start to the Administrator.

EPA considers this to be an unnecessary requirement and eliminates it.

§86.1336-84(c) Clarified action to be taken during engine stalling.

This amendment represents a clarification of the earlier test procedure.

§86.1337-84(a)(10) and (21) Added requirement that sampling systems continue sampling until system response times have elapsed.

This amendment goes hand in hand with EPA's allowance for longer sampling system response times. This amendment assures that emissions generated by the engine are not lost at the very end of the test, as they would be if sampling systems with longer response times were shut down simultaneously with the engine.

§86.1337-84(b) Eliminated mandatory time increments for emission tests using more than one bag or mode.

EPA sees no need to require manufacturers to conform with specific time increments for modal analysis.

§86.1337-84(c) Added clarification of conditions under which an engine on which a void test was run may be recooled and retested.

This amendment represents a clarification of the earlier procedure.

§86.1338-84(a)(2) Added procedure for calibration below 15 percent of analyzer's full scale.

This procedure was requested by the industry to provide clarification of the specific conditions and applicable procedures for calibrating analyzers below 15 percent of full scale. This amendment represents no net change in procedure accuracy.

§86.1338-84(b)(1) Clarified permissible deviations from requirement that analyzer response remain between 15 and 100 percent of full scale.

This amendment represents a clarification of the earlier procedure, as requested by the industry.

§86.1340-84(a)(1) Clarified stability requirement for background sample response.

This amendment corrects an inadvertantly stringent specification contained within the original test procedure; a more reasonable stability requirement is promulgated.

§86.1340-84(a)(2) Eliminated need to store all ADC input; only an average integrated value need be stored.

This amendment corrects an overly burdensome requirement contained within the original test procedure. EPA now requires only that a manufacturer record a single emission value for a given test cycle, and not the second-by-second ADC output. (This is conceptually identical to the requirements imposed for bag sampling.)

§86.1340-84(d) and (e) Reorganized the procedures for clarity, and modified continuous HC sampling and hang-up check procedures.

This amendment represents a clarification of the original test procedure.

§86.1340-84(f) Changed hang-up check to include entire sample probe.

This technical amendment makes the hang-up check more technically correct, and better able to verify the integrity of the entire sample probe.

§86.1341-84(h) Added to address the handling of closed rack torque reference points in cycle validation. Clarified method of validation for BHP points when torque reference calls for motoring.

This amendment addresses the treatment of certain feedback points in the cycle performance regression analyses; these specific points and their treatment in the regressions were inadvertantly ignored in the original test procedure.

§86.1341-84 Figure N84-11 — Clarified regression analysis point deletions for diesels at closed rack; specifically allowed use of clutch. Original Figure N84-11 deleted, and original Figure N84-12 substituted in its place. Regression line tolerances clarified to represent a percentage of power-map values. An additional torque and power deletion added if closed throttle and torque feedback greater than torque reference

These amendments reflect clarifications, elimination of an unnecessary figure, and the inclusion of an additional point deletion allowance which EPA has determined to be appropriate.

§86.1342-84(c) — Corrected omission of humidity correction factor from flow compensated NOx measurement calculations.

This corrects an error in the earlier test procedure, and reflects EPA's provision of a humidity correction factor for diesel engines.

§86.1342-84(d)(3) — Added calculation for mass fuel flow to be used in approximating dilute exhaust CO_2.

This option, requested by EMA, permits a manufacturer to measure mass fuel consumption in lieu of CO_2 exhaust concentration. Either of the two measurements is acceptable for calculation of exhaust emissions, however, the equipment for measuring mass fuel flow is much less expensive to procure and maintain.

§86.1342-84(d)(5) and (6) — Added dilution factor calculation based upon approximated dilute exhaust CO_2. Specified humidity correction factors for diesel engines.

This additional calculation was necessitated by the allowance that mass fuel flow measurement be substituted for exhaust CO_2 measurement. In addition, the newly provided humidity correction factor for diesel engines is specifically included here.

§86.1342-84(i) — Added calculations for dry to wet exhaust concentration conversion, accounting for both dilution air humidity and approximate exhaust H_2O concentration.

This correction calculation was suggested by the EMA as an improvement. EPA concurs with their recommendation, and believes that the omission of this calculation from the earlier procedure was an error.

§86.1344-84(e)(6) Added requirement for description of mapping technique.

This requirement has been added by EPA to ensure that the manufacturers inform EPA in their application for certification if an alternate mapping technique has been used.

Appendix I(f)(1) An optional driving cycle for heavy-duty gasoline engines has been added.

(See Chapter 3.A.3 of this Summary and Analysis of Comments.)

B. Subpart I - Heavy-Duty Diesel Engine Smoke Test Procedure

Overview of Technical Amendments

The following sections from 40 CFR Part 86 (as printed July 1, 1982) are being superseded, and are hereby deleted:

Sections

86.877-1	86.877-13
86.877-2	86.877-14
86.877-3	86.879-5
86.877-4	86.879-6
86.877-5	86.879-7
86.877-6	86.879-8
86.877-7	86.879-9
86.877-8	86.879-10
86.877-9	86.879-11
86.877-10	86.879-12
86.877-11	86.879-13
86.877-12	86.879-14

The following sections are being added to 40 CFR Part 86 (as printed July 1, 1982). Aside from changes in references, specific allowances for the use of automated data collection equipment and electric dynamometers, and changes to permit consistency with Subpart N and other 1984 rules, no significant change distinguishes this procedure from earlier versions:

Sections

86.884-1 General Applicability.
86.884-2 Definitions.
86.884-3 Abbreviations.
86.884-4 Section numbering.
86.884-5 Test procedure.
86.884-6 Diesel fuel specifications.
86.884-7 Dynamometer operation cycle for smoke emission tests.
86.884-8 Dynamometer and engine equipment.
86.884-9 Smoke measurement system.
86.884-10 Information.
86.884-11 Instrument checks.
86.884-12 Test run.
86.884-13 Data analysis.
86.884-14 Calculations.

C. Subpart P - Heavy-Duty Gasoline Engine and Light-Duty Gasoline Truck Idle Test Procedure

Overview of Technical Amendments

In general, the following changes were made throughout the entire subpart:

1. All references to diesels were deleted; references to and procedures for light-duty trucks were added.

2. Miscellaneous clarifications were made.

3. References to Subparts N, B, and D were clarified.

4. Requirements were made consistent with Subparts N and B where possible.

Specific Amendments

The following sections from 40 CFR Part 86 Subpart P were modified enough to merit specific mention. These modifications represent no substantive change to the fundamental test procedure:

86.1514-84 Analyzer gas specifications made consistent with Subpart N and B.

EPA considers it to be unnecessary to have differential requirements for calibration and span gases for all emission test procedures applicable to any given vehicle or engine. This amendment makes analyzer gas requirements consistent between applicable test procedures.

86.1516-84(b) Minimum calibration frequency changed from weekly to monthly as in Subpart N.

This amendment makes calibration procedures consistent between subparts, such that the same equipment can be used for either test.

86.1516-84(c) Check interval changed from daily to before each test.

This amendment makes calibration procedures consistent between subparts, such that the same equipment can be used for either test.

86.1527-84(a) Clarified test run sequence, especially for light-duty trucks.

The earlier test procedure addressed light-duty trucks only by reference, and left much of the test sequence unspecified. This amendment corrects that omission, and provides a specific test sequence for light-duty trucks.

86.1527-84(b) Ambient test cell requirements made consistent with those of Subpart N and B.

This amendment allows the use of the same equipment in the same test cells for testing conducted under either subpart.

86.1542-84 Information requirements made consistent with Subparts N and B.

This amendment allows the manufacturer to more easily combine test results in a single application for certification.

12. Issue: Possible "Migration" from Class IIB to Class III

Summary of the Issue

In the March 1983 staff paper, EPA proposed a split-class approach to HDGE HC/CO control. In that proposal, HDGEs intended for use in Class IIB and III applications (up to 14,000 lbs. GVW) would be required to meet the statutory standards of 1.3 HC/15.5 CO in 1987, while HDGEs intended for use in heavier applications (over 14,000 lbs. GVW) would continue to meet non-catalyst standards (assumed to be 2.5 HC/35 CO). Commenters disagreed with the choice of "break point," maintaining that Class III (10,001-14,000 lbs. GVW) HDGEs should be included with the heavier HDGE applications, and therefore allowed to meet the non-catalyst standards rather than the statutory standards.

The critical problem with lowering the "break point," as advocated in the comments, is the possibility that LDTs in the upper portion of the Class IIB weight range (8,501-10,000 lbs. GVW) could be slightly "redesigned" so as to be heavy enough to be included in Class III. This "migration" of Class IIB vehicles into Class III, thereby avoiding the catalyst-forcing statutory HC/CO standards, has been discussed in some detail elsewhere.[1] The discussion below is limited to where the classes should be split, and how the potential problem of "migration" should be addressed.

Summary of the Comments

Of the comments submitted in response to the staff paper, only Ford and GM specifically addressed the issue of where the "break point" should be set under EPA's proposed split-class approach.

Ford suggested that a more logical "break point" would be at 10,000 lbs. GVW; in other words, Class IIB HDGEs would meet the catalyst-forcing statutory standards while all other HDGEs (Classes III-VIII) would meet the proposed non-catalyst standards. Ford acknowledged the validity of EPA's concern over "migration" under this HDGE split, but maintained that HDGEs in dual rear-wheel and fifth-wheel ("pop-truck") Class III applications are more appropriately grouped with the heavier HDGEs. This is due to the in-use service environment of such vehicles, a significant portion of which is spent operating at full-load, WOT conditions. Ford indicated that the high temperatures characteristic of these conditions render catalyst use infeasible.

General Motors responded to the staff paper with an entirely new proposal, maintaining the general notion of splitting HDGEs into two groups but having little else in common with the split-class approach described in the staff paper. Other aspects of the GM proposal are dealt with in detail elsewhere;[1] only the choice of "break point" is discussed here.

General Motors paralled Ford in proposing that the "break point" be set at 10,000 lbs. GVW, and claimed that its proposal is responsive to two of the concerns expressed by EPA. As identified by GM from the staff paper, these concerns are: First, that the majority of HDGEs as currently defined be subject to the catalyst-based statutory standards; and second, that the air quality benefits resulting from implementation of the statutory standards not be significantly reduced by "migration" of HDGEs below, but close to, the "break point" to just above that point.

General Motors noted that HDGEs in Class IIB represent about 65 percent of all HDGEs; thus, the IIB/III-VIII "break point" would continue to require a majority of HDGEs to be catalyst-equipped. Citing the small HDGE sales in Class III, GM stated that "insignificant air quality improvement" would occur, relative to its proposal, if the "break point" is set at 14,000 lbs. GVW. GM also indicated, although less specifically, a concern similar to that expressed by Ford: that the use patterns and operating conditions characteristic of Class III applications are likely to result in higher temperatures than catalyst technology can endure.

General Motors also claimed that not only would there not be a "migration" problem, but that there would actually be strong incentives not to move vehicles to higher GVW classes. As justification for this assertion, GM states that the cost increase for catalyst technology on HDGEs meeting the statutory standards would be comparable to the cost increase for added non-catalyst emission control technology on the heavier HDGEs. In addition, raising the GVW would involve cost increases for the upgrading of other vehicle components (e.g., springs, axles), thus further reducing any possible motivation for vehicles to "migrate" from Class IIB to Class III.

Analysis of the Comments

EPA acknowledges that the air quality impact of control of HC and CO to catalyst-forcing levels for HDGEs in Class III applications will be small compared to the control from Class IIB vehicles (because of sales). The selection of 14,000 lbs. GVW as the "break point" was based on EPA analysis of where

HDGE types change, in terms of use and application. EPA was also concerned over possible HDGE "migration" if the dividing line between catalyst-based and non-catalyst based standards were set at the lower level (10,000 lbs. GVW).

The comment by Ford about the similarity of use patterns and operating environments for some Class III applications and the Classes IV-VIII applications is a valid concern. However, EPA does not believe that lowering the "break point" to 10,000 lbs. GVW is the best approach to dealing with this concern, since it fails to address how "migration" might be avoided. A method of accounting for both EPA's concern over "migration," and Ford's concern over the inappropriateness of requiring catalyst technology on some HDGEs in Class III applications, is to maintain the "break point" as EPA proposed (14,000 lbs. GVW) while providing for reclassification of a limited number of HDGE configurations. This is explained in more detail below.

The disincentives to "migration" cited in the GM comments are based on assumptions contained in the GM counter-proposal, not on the EPA split-class proposal. While the arguments may sound reasonable on first examination, EPA's concerns over "migration" are not alleviated. Previous "migration" of Class IIA vehicles up to Class IIB, to avoid more stringent emission standards and fuel economy regulations, demonstrates the validity of EPA's concern. This earlier trend of "migration" is evidenced by the relatively large concentration of vehicles with GVWs in the 8,501-8,600 lbs. range,[1] which can logically be assumed to have "migrated" above 8,500 lbs. GVW for the reasons cited above.

In EPA's analysis of the GM counter-proposal,[1] an attempt to estimate the potential magnitude of the "migration" of Class IIB into Class III is made. Although these estimates must be considered "soft," due to the unavailability of sales data for Class IIB alone, they do provide an estimate for consideration. The analysis showed that roughly 70 percent of Class IIB vehicles have GVWs of 9,000 lbs. or more, which means that they could conceivably be redesigned so as to enter Class III. How much actual "migration" would occur if the "break point" were set at 10,000 lbs. GVW is difficult to predict with any certainty. However, EPA believes that the potential for migration is strong because of the number of vehicles sold near the Class IIB upper GVW limit, coupled with a desire by manufacturers to apply catalyst systems to as few vehicles as possible (if for no other reason than because of an anticipated strong buyer preference for non-catalyst vehicles). Further, EPA finds the risk of migration avoidable.

EPA believes that the concerns of both the Agency and the industry over the inclusion of Class III vehicles in the proposed new Classes IIB-III subcategory can be adequately addressed by a fairly simple modification to the approach developed in the staff paper. The "break point" between catalyst and non-catalyst HDGES should remain at 14,000 lbs. GVW, as proposed by the staff paper. However, whereas that proposal effectively contained no exemption provisions, EPA recommends modifying the proposal so that manufacturers would be permitted to reclassify a limited portion of their Classes IIB and III configurations to Class IV. The choice of configurations to be reclassified would be left to the discretion of the manufacturers, providing them maximum flexibility in choosing the configurations where catalyst application would be the most difficult. However, the size of the reclassified group would have to be limited by EPA to insure that no significant environmental losses would occur.

The limit on reclassification would be expressed as a percentage of all sales in Classes IIB and III. Based on the actual 1980 and projected 1990 sales data used in the staff paper, this limit would be in the range of 2 to 7 percent, approximating Class III sales as a fraction of combined sales in Classes IIB and III. There is a tendency in the sales projections for this ratio to increase slowly over time; however, as was noted by Ford in its comments, it is not necessary for <u>all</u> Class III HDGEs to be exempted from the statutory standards. Balancing these considerations, EPA has decided to limit to 5 percent of combined Classes IIB and III sales the reclassification of Classes IIB and III HDGEs to Class IV.

Under the split-class approach, modified as detailed above, there should be little change of air quality benefits from the staff paper proposal, while the legitimate concerns of the manufacturers over a limited number of Class III applications would be addressed. In fact, the manufacturers will gain an added degree of flexibility in compliance with the new regulations. They will be able to minimize their costs by reclassifying the more severe applications.

<u>Conclusions</u>

EPA will maintain the LHDGE/HDGE "break point" at 14,000 lbs. GVW, as was proposed in the staff paper. EPA will include provisions for up to 5 percent of combined sales of HDGEs in Classes IIB and III to be reclassified and certified to non-catalyst levels, on a configuration-specific basis.

References

1. Evaluation of General Motors' Heavy-Duty Engine Proposal, EPA Memo from Chester J. France, Standards Development and Support Branch, to Richard D. Wilson, Office of Mobile Sources, May 16, 1983.

13. Issue: Diesel Engine Closed Crankcase Requirements

Summary of the Issue

The regulations promulgated on January 21, 1980 presently require that all naturally aspirated heavy-duty diesel engines have closed crankcases (i.e., zero crankcase emissions are to be discharged into the ambient atmosphere).

Summary of the Comments

General Motors claimed that no technology was available to safely allow closing of the crankcase for 2-stroke heavy-duty diesel engines. General Motors' primary concern is that the internal fuel system used in these engines may leak. This would create a safety problem if fuel overflows into the engine intake through the crankcase ventilation system and causes an uncontrolled engine runaway.

General Motors also noted that 2-stroke engines require a blower to induct intake air into the cylinders. To route crankcase emissions into the intake air would require either an expensive pumping system to force the crankcase vapors into the higher pressure air downstream of the intake blower, or, if crankcase vapors were ventilated into the intake air upstream of the blower, fouling and deterioration of the blower may occur. These problems led EPA to decide not to finalize closed crankcase requirements for turbocharged diesel engines in December of 1979.

General Motors recommended that the closed crankcase requirement for these engines be rescinded.

Analysis of the Comments

There are two aspects to the closed crankcase issue for 2-stroke HDDEs: feasibility and cost effectiveness.

EPA notes that GM engine families, other than 2-stroke engines, utilize internal fuel systems. GM has stated to EPA that a safe closed crankcase system for its internally fueled 8.2L engine, while presenting an initial challenge to designers, will likely be available for the 1985 model year. Given GM's claim that a feasible closed crankcase system can be applied to its 8.2L engine in 1985, it is difficult to accept GM's assertion that the application of such systems to 2-stroke engines will be permanently infeasible. On the strict basis of feasibility, EPA finds no merit in GM's request that 2-stroke engines be permanently excluded from closed crankcase requirements.

On the other hand, the parallel drawn by GM between 2-stroke and turbocharged engines is valid. Both engines would require similar closed crankcase systems in the sense that a more expensive pumping system is needed to overcome the high pressure intake air. Otherwise, turbocharger/blower fouling may occur if crankcase effluents are added to the intake air upstream of the turbocharger/blower. EPA recognized this problem in the January 21, 1980 rulemaking: such a system for turbocharged engines would be roughly ten times the cost of a closed crankcase system for naturally aspirated engines. For this reason, EPA did not finalize closed crankcase requirements for turbocharged engines at that time. It was not a question of feasibility, but rather an acknowledgement of the poor cost effectiveness of the requirement.

Failure to include all engines which rely upon forced induction of intake air with this deferral of closed crankcase requirements occurred mainly because the manufacturers did not raise it as a significant issue. (GM and other manufacturers never raised such an issue during the earlier rulemaking.) However, it would now be technically appropriate to make this change to the regulations. Furthermore, the number of engines affected by this (i.e., the number of naturally aspirated 2-stroke engines) is quite small, and getting smaller as turbochargers become more universally adopted. (Only 3.3 percent of GM's 1983 sales were naturally aspirated 2-stroke engines; no other manufacturer makes 2-stroke engines.) Given this small impact, and given the technological similarity between the 2-stroke and turbocharged engines with respect to closing the crankcase, EPA concurs that closed crankcase requirements should not apply to 2-stroke engines until a similar requirement for turbocharged engines is promulgated. This conclusion is based entirely on the relative cost effectiveness of closing the crankcase on engines which require turbochargers, blowers, etc., to induct intake air.

Conclusion

The closed crankcase requirements should not apply to 1985 and later model year heavy-duty diesel engines which require forced induction of intake air (e.g., by turbochargers, blowers, etc.).

Appendix A

Draft Technological Feasibility Analysis from the NPRM "Revised Gaseous Emissions Regulations for 1984 and Later Model Year Light-Duty Trucks and Heavy-Duty Engines"

CHAPTER II

TECHNOLOGICAL FEASIBILITY/ ATTAINABLE NON-CATALYST STANDARDS

A. Introduction

In this chapter, EPA analyzes available technologies and projects what levels of HC and CO emissions for heavy-duty gasoline (HDG) engines are attainable for 1984, assuming that oxidation catalysts are not employed.

B. Current HC and CO Emission Rates

To properly evaluate potential non-catalyst emission reductions from HDG engines, current emission rates must be reviewed. Because absolute emission levels are inherently affected by the test procedure over which they are measured, a review of the transient emission test is appropriate.

1. Overview: The Transient Test

The transient test is performed on a computer-controlled engine dynamometer. During the test, the engine is driven through continuously-varying speeds and loads according to prescribed cycles. These speed and load cycles were developed from in vehicle performance data taken from 57 urban HDG trucks: 30 in the joint industry/EPA CAPE-21 study in New York City, and 27 in the EPA-conducted Los Angeles CAPE-21 study. These trucks were actual commercial vehicles operated by their own drivers; the performance data was taken in the course of their daily business. These data were then used to generate driving cycles representative of the input data.

There are several key aspects of the transient test:

a. It is engine specific,

b. It is composed of subcycles, each of which retains the characteristic driving patterns of specific urban localities, and,

c. It is performed on a "cold" engine, and then repeated with the engine in a warmed-up state.

Each of the above characteristics is critical in evaluating current and future emission trends.

Engine specific means that the cycles are defined in terms of percent speed and percent load, i.e., any two engines are required to deliver identical percent powers throughout the cycle even though their absolute power levels may be different. This, and the fact that emissions are expressed as mass per output work

(work is simply power multiplied by the time at that power), make emission results between engines comparable, regardless of their specific rated power and varying performance characteristics.

Secondly, the cycle is actually four subcycles joined end to end, each one characteristic of a particular geographic area and type of driving:

Subcycle	Duration (sec)	Characteristics
1. New York Non-Freeway (NYNF)	272	low power; stop-and-go; 45% idle; avg. spd. 7.8 mph
2. Los Angeles Non-Freeway (LANF)	309	moderate power, transient; 26% idle; avg. spd. 15.1 mph
3. Los Angeles Freeway (LAF)	316	high-speed, high-power cruising; avg. spd. 45.54 mph
4. New York Non-Freeway (NYNF)	272	repeat of 1.

Each subcycle demands different performance from the engine, and produces different absolute emission levels. These performance demands can be isolated and their emissions impact reasonably estimated.

Thirdly, the heavy-duty engine dynamometer test is similar to the light-duty vehicle test in that the total emission results are derived from a weighted average of a "cold" engine cycle and a hot engine cycle. For the heavy-duty test, the cold start emission cycle consists of the above four subcycles (NYNF, LANF, LAF, NYNF), and is weighted 1/7 of the total; the hot start cycle is identical to the cold, begins 20 minutes after shut down of the engine from the cold start, and is weighted 6/7 of the total. These weighting factors were derived from the observed in-use ratio of cold starts to hot starts in the CAPE-21 survey. Since a cold engine characteristically emits higher amounts of HC and CO, the cold start cycle is significant when discussing current and future emission levels.

2. Current Technology Engines

Table II-1 presents a list of 1979 MY HDG engines tested by EPA on the transient cycle. Table II-2 presents subcycle by subcycle HC emission breakdowns for each engine, along with a percent contribution of each subcycle to the total emission results. Table II-3 presents the same data for CO.

Immediately noticeable in Table II-1 are the high levels of HC and CO emissions. Note that the engines were certified for 1979 at 1.5 g/BHP-hr HC and 25 g/BHP-hr CO, but on the 9-mode steady-state test procedure. In complying with any motor vehicle emission standard, the design approach is to match the engine calibration and emission control system to the test procedure itself. This is the case in light-duty (see Reference 2), and indeed in heavy-duty. Table II-4 presents comparative HC and CO emission data for both transient and 9-mode test procedures for the current technology (1979) engine baseline. The large differences in measured emissions are explainable by the readily identifiable differences in required engine performance under each test.

3. The 9-Mode Test

The 9-mode test procedure consists of nine steady state engine operating modes which are weighted into a composite emission number:

Mode	Speed (RPM)	% Power	Weighting Factor
1	Idle	0	.232
2	2000	25	.007
3	2000	55	.147
4	2000	25	.077
5	2000	10	.057
6	2000	25	.077
7	2000	90	.113
8	2000	25	.007
9	2000	Closed Throttle	.143

The 9-mode is performed with the engine in a warmed-up state, at only one engine speed (except idle). To date, it can be firmly stated that on all current production engines all efforts at emission control on HDG engines have been directed primarily at these modes.

There are three major areas of engine operation which the transient test contains, but not the 9-mode:

a. Full power operation;

b. Transient operation, at all speeds and loads;

c. Cold engine operation.

These areas give rise to the measurable emission differences, and reflect where control technology will need to be directed for 1984. In this analysis we will show that full power (power enriched) LA Freeway modes are the major source of CO emissions in current technology engines, and also a significant source of HC on the higher emitting engines. Secondly, the major source of HC on the lower HC emitting engines will be shown to be the cold engine operation. Finally, on the lower-emitting engines, it will be shown that non-cold start HC and the remaining CO emissions are not as attributable to any one mode or source, and are primarily relatable to inadequately controlled mixture calibration as the engine undergoes transients at all speeds and loads throughout the entire test cycle.

4. Full Power Operation

Under wide open throttle (WOT) conditions, additional fuel is added to the combustion mixture. This power enrichment causes richer than stoichiometric mixtures, thereby promoting power and driveability, but drastically increasing unburned fuel (HC) and partially oxidized fuel (CO) emissions due to lack of oxygen. Present day engines certified to the 9-mode were emission controlled primarily up to 90 percent power (at only a single speed); note that current technology engine power valves are calibrated to cause power enrichment above 90 percent power. Thus, full power emissions on current technology engines are uncontrolled.

This observation is demonstrated by the data presented in Tables II-2 and II-3. In both tables, data from all twelve current technology engines tested at EPA are presented. In addition, the engines are also grouped into three categories: high, medium, and low emitters of a given pollutant. Note mode 7, the LA Freeway (LAF) in the hot-start portion of the test: 29.6 to 65.7 percent of brake specific CO (BSCO) emissions are attributable to this high-power segment. More interesting are the trends observed in segment percentage contributions from the highto the low-emitting engines. As the average composite BSCO emissions go from 105.5 g/BHP-hr (higher emitters) to 46.1 (lower emitters), i.e., a 2.3 fold decrease, all other subcycle model percentages increase by approximately two-fold <u>except</u> for the LAF mode, which decreases in contributing percentage from 56.3 to 36.7 percent (i.e., a lower percentage of a lower composite number). Had all modes decreased proportionally, the model percentages should remain constant. Clearly the major difference between high and lower CO engines is the amount of CO generated during the LAF segment. This is primarily a result of power enrichment in the carburetor during the LAF's characteristic high speed, high power operation. (Perhaps most indicative is the actual mass of CO generated during the LAF segment. Note in Table II-3 that total grams of CO generated in the LAF segment are 50-650 percent higher than those of the next highest hot start segment.)

The data for HC (Table II-2) is less dramatic with regards to LAF dominance, but the trends are nevertheless the same. Every high CO engine, (i.e, those with LAF dominance of CO emissions) also has dominant LAF HC emissions (ranging from 23.7 to 36.0 percent total contribution). This is logical since in this operational mode both emissions arise primarily from inadequate oxygen for total combustion in the fuel-enriched mixture. Again, the lower the total HC emissions are, the lesser the percent contribution of the LAF segment to that total.

In summary, power enrichment occurs at the high power points throughout the entire transient test cycle, but the majority of this high power operation is found in the LA Freeway segment. Emissions performance over this segment is the major differentiating factor between lower and higher emitting engines. Control or power enrichment is the first and most effective step in reducing CO emissions with or without a catalyst. This will be discussed further below.

5. Transient Operation/All Speeds and Loads

As the LAF emissions contribution drops when going from the higher to lower emitting engines, the contribution from other segments tend to increase until no single segment is dominant. (The obvious exception to this is cold start HC, which is discussed below.) Aside from certain physical factors,* these emissions arise from less than accurate fuel metering and mixing as the engine drives over the entire test cycle. If the fuel flow does not precisely match the engine inlet air flow at any instant in time, then too lean or too rich mixture conditions prevail, along with ensuing lean misfire (high HC) or incomplete combustion (high HC and CO). This matching is complicated by the inevitable need to closely match the fuel and air flows at continually varying speeds and loads while also maintaining power and driveability. All current technology engines were emission optimized at idle, and at eight different steady-state power modes at 2000 RPM. This represented a reasonably simple design/calibration problem, as evidenced by the engines' emission performance over the 9-mode test. Once outside that limited regime of emission-optimized modes, however, such as on the road or on the transient test, emissions remain virtually uncontrolled. Little design attention with respect to emissions has been given to the majority of the engines' operating ranges.

Precise matching of fuel and air flows under varying conditions, including transient enrichment by the accelerator pump for driveability, is a major emission-related problem of mixture control. Another is the problem of achieving as homogeneous (perfectly mixed) a fuel/air (F/A) mixture as possible. Incomplete mixing (including liquid fuel deposition on the manifold or combustion chamber walls) produces localized pockets of rich and lean mixtures, resulting in an overall increase in HC and CO emissions. Complete mixing is also critical to achieving uniform A/F ratios from cylinder to cylinder, again to optimize overall emission performance.

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* Combustion chamber design affects wall quenching. Inlet manifold design affects mixture distribution between cylinders, fuel deposition in the manifold, and heat exchange characteristics. All of these in turn affect HC and CO emissions.

The above problems are not new, are well recognized, and have already been addressed in the light-duty passenger car fleet. Experience with the light-duty fleet has indicated, however, that there exists a definite limit to the amount of HC and CO emission reductions achieveable through recalibration before power, driveability, and/or fuel economy become unacceptable. For this reason, catalysts become inevitable at lower emission standards, both for their effectivenss and the flexibility in engine calibration their effectiveness permits.

6. Cold Engine Operation

Cold start emissions are substantially higher than those of a fully warmed-up engine, and usually require separate attention during control system design. Again referring to Tables II-2 and II-3, we note that cold start HC contributions are high, and become dominant at lower overall levels of HC emissions. Cold start CO on the other hand has a relatively minor effect on an overall basis. This phenomenom is typical, though perhaps exaggerated by the lack of design control in the past, and is attributable to the fact that a very rich mixture is needed for starting and driveability in a cold engine, to compensate for deposition of a large part of the fuel on cold manifold walls. This rich mixture is provided by the choke mechanism, either manual or automatic. Emissions arise both from this overall rich mixture, misfire, and from the eventual evaporation of the condensed fuel. Emissions have not been a design constraint in the past for cold starting, only startability, driveability, and power. The transient test procedure itself is demanding, requiring both emission control and high power driveability early in the cold start cycle.

C. Available Control Techniques

1. Overview

Widespread introduction of new non-catalyst technologies is assumed to be an unrealistic scenario for the 1984 model year. This is a function of the remaining leadtime, and cost - the intent of this rulemaking is to ease the capital expenditure burden on the industry. Technologies which EPA expects to be implemented for 1984 will not be new, but rather will represent refinements, recalibrations, and optimizations of current technologies.

2. Improvements to Fuel Metering

By and large, fuel metering improvements will be the single most effective strategy for reducing overall HC and CO emissions in 1984 engines, especially when optimized for the transient test. These improvements include modifications to carburetors to achieve more precise F/A ratio control, and recalibration to leaner F/A ratios on an overall basis, and especially under transient conditions and WOT.

Figure II-1 presents the CO emission distribution of the 1979 baseline engines. Note that two mutually exclusive sets of carburetors are found above and below 70 grams/BHP-hr, representing higher and lower emitting engines. Some carburetors (those below 70 g/BHP-hr) meter fuel more accurately under transient conditions even though also optimized for the 9-mode. Power enrichment, sometimes observed at 4-6 percent CO (40,000 to 60,000 ppm in the raw exhaust) contributes substantially to these CO levels, as shown above in Table II-3. At any rate, we infer from Figure II-1 that since two groups of carburetors produce two radically different emission rates on a test procedure for which neither was optimized, the higher emitting group is unrepresentative of current technology and should not be considered a realistic starting point when extrapolating achieveable emission reductions. They represent excessive power enrichment/inaccurate fuel metering producing twice the CO emissions of other engines of equivalent power and displacement. The realistic current technology CO baseline is, therefore, presumed to be in the range of 40-60 g/BHP-hr. It is from this range downward in which development work will be concentrated.

The prime result of recalibration will need to be leaner mixture calibration, and leaner WOT and transient enrichment, thereby reducing both HC and CO emissions.

3. Improved Mixture Distribution

As overall calibrations get leaner, it becomes more important from a power, driveability, and emissions standpoint that the F/A mixture be as homogeneously mixed as possible and the mixture distribution to each cylinder is uniform. Localized rich or lean "pockets" in the mixture should be eliminated by the time it enters the cylinder. Assuring uniform F/A mixture distribution to each cylinder is also important. Too lean a mixture in one or more cylinders will force recalibration to a richer operating point to accommodate the needs in that cylinder, which will in turn cause too rich a mixture in other cylinders.

This is essentially a problem of improving the mixing of air and fuel in the manifold prior to cylinder induction. The liquid fuel must be vaporized and then mixed, requiring heat energy and substantial turbulence. Deferring the problem of cold starting until later, heat energy arises from the air itself and from the warm manifold. Improvements would come from redesign of the manifold to increase turbulent mixing, and to increase heat transfer (perhaps by heating intake air by drawing it across the exhaust manifold) to the intake air or air/fuel mixture.

4. Other Physical Modifications

Other physical changes to the engine have been proven to reduce unburned fuel emissions, such as decreasing surface-to-volume ratio of the combustion chamber to minimize wall quenching, reductions in cylinder "dead" volume, etc. Although these may be per formed on some engine families, we do not consider fleetwide physical redesign of engine combustion chambers for all families to be realistic or necessary for 1984.

5. Other Calibration Optimizations

As mixture calibration optimization reaches its limit with respect to attainable reductions, other calibrations - notably spark timing - can be utilized to further reduce HC and CO. Ironically, these reductions are made possible by the other 1984 MY emission standard for heavy-duty engines: the NOx standard of 10.7 grams/BHP-hr. NOx emissions at this level are relatively uncontrolled, and will allow ignition timing calibration to be set near MBT* - the most efficient calibrations. The higher NOx standard permits both lean mixtures and optimum timing advance - both of which increase NOx but decrease HC and CO emissions and fuel consumption.

Furthermore, spark timing can also be optimized for the cold start portion transient test procedure. The light duty fleet currently uses electronically-controlled spark timing to optimize ignition under all engine operating conditions in the Federal Test Cycle to minimize emissions and maximize fuel economy. The methodology and technology is entirely applicable, if necessary, to HDG engines on the transient test.

6. Improved Warm-up Characteristics

As emission levels decrease with mixture and ignition timing optimizations, the limiting factor for HC reductions is clearly the engine's performance on the cold start portion of the transient test. As Table II-2 above indicated, cold start HC emissions are the dominant fraction of engine-out HC.

Two strategies exist for reducing cold start emissions: restrict the amount of cold mixture enrichment, and increase the warm-up rate of the engine. The former is straightforward, and limited by the amount of leaning a cold engine can withstand and still maintain the high driveability and performance both the road and the transient test require. This is done by choke recalibration. Increasing the warm-up rate of the engine can be accomplished in primarily two ways: decrease the efficiency of the overall combustion cycle, and use exhaust gas heat to rapidly warm the intake manifold and/or intake air. Cycle efficiency reductions are best achieved by changing spark timing as a function of engine temperature: less efficient spark timing calibrations reduce engine efficiency, and increase the amount of waste heat rejected to the combustion products and thereby conducted to the engine itself. The result is a faster warm-up; less time spent in a cold state reduces cold emissions.

* "MBT" denotes the minimum timing retard (i.e. maximum timing advance) at which maximum power is obtained without inducing knock reactions.

Cold start HC emissions, as elaborated above, are presently uncontrolled, and generally dominate at lower overall HC emission levels. Table II-5 lists current technology engines, and the percent increase in composite total transient test HC and CO emissions attributable to the cold start cycle. (The cold start cycle is identical in every way to the hot cycle, with the sole exception of engine temperature.) From this we can infer the amount of emissions generated by the "cold"* engine temperature. Figure II-2 graphically portrays the percentage attributable to cold engine temperature versus the total composite test result, and illustrates the general trend of increasing impact of cold HC emissions with lower overall HC emission rates. (Note that there are exceptions to the trend). All of the 1979 baseline engines tested by EPA were equipped with automatic chokes; the high degree of scatter in the Table II-5 data indicates that varying choke calibrations are possible. Since the varying engine calibrations were not optimized for either a transient test or a cold start, the available data does not lend itself to determining the exact contribution of the cold start to overall test results at any given emission level. The data do indicate, however, that it can be significant (probably 10-40 percent). The real question is to what degree cold start HC emissions can be reduced by choke recalibration/improved warm-up. Experience tells us that significant reductions are achievable from uncontrolled engines.

7. <u>Summary of Possible Control Techniques</u>

Based on the discussion above EPA has identified a number of potential means of reducing HC and CO emissions from HDG engines. These are summarized below.

a. <u>Carburetion</u> - modifications and improvements to the power enrichment, accelerator pump, and general fuel metering systems.

b. <u>Calibrations</u> - spark timing, A/F ratio, and EGR flow rate calibrations.

c. <u>Manifold/Combustion Chamber Redesign</u> - intake manifolds could be redesigned to improve the homogeneity of the F/A ratio. Combustion chamber surface-to-volume ratio could be decreased and cylinder dead volume minimized to lessen fuel quenching on cylinder walls.

d. <u>Air Injection System</u> - Increased air injection to the exhaust manifolds will increase the HC and CO oxidation. This system could be further improved by an air modulation system and possible recalibrations of the pressure relief and diverter valves. Some exhaust manifold modifications may also aid the efficiency of the air injection system.

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* "Cold," for laboratory test procedure purposes, is a temperature between 68° and 86°F.

e. Automatic Choke - the use of a properly calibrated automatic choke would decrease cold start HC and CO emissions and improve warm-up time.

f. Early Fuel Evaporation (EFE) - this system involves the use of exhaust gases to warm the air-fuel mixture by directing some of the exhaust gases through a passage below the carburetor. A warmer A/F mixture improves the fuel distribution to the cylinders and results in lower emission levels and shorter warm-up periods.

g. Heated Air Intake - heated air intake or a modulated air cleaner system uses exhaust gases to warm the intake air to the carburetor. This improves engine warm-up time and reduces emissions by allowing leaner carburetor calibrations.

h. Exhaust Gas Recirculation (EGR) - EGR primarily used for NOx control, can also be beneficial with regards to HC control. Besides its overall leaning effect on the mixture, it also permits recombustion of a percentage of the exhaust gases. Similarily, increased valve overlap works as a form of "internal EGR."

The effectiveness of modifications and hardware of this type has been demonstrated in the light-duty vehicle and light-duty truck fleets for several years. These control strategies should be available for the 1984 model year HDG engines and should provide substantial HC and CO reductions over current levels.

8. Tradeoffs

The emission control strategies discussed above have tradeoffs with respect to fuel economy, power, and driveability. Leaner mixtures, less power enrichment, and quicker engine warm-up all improve fuel economy, but when carried to excessive degree could impair power and driveability. An increase in air injection would also cause a small fuel economy loss. EPA now believes that the fuel economy impacts of these regulations will be basically neutral. The limits to emission reduction will be determined equally by power requirements and driveability needs in addition to any fuel economy concerns.

D. Attainable Reductions/Proposed Emission Standards

As described above, several relatively simple and effective means of emission control are available. At this time, EPA has limited data as to the absolute effectiveness of a given technique on heavy-duty gasoline engines. For example, no testing has been performed to date on a current engine where mixtures were leaned out, spark timing curves optimized, power enrichment limited, and fast warm-ups or fast opening chokes were initiated. It is difficult to quantitatively predict attainable emission reductions without results of such testing.

One approach to deriving achievable standards would be to use an engineering estimate of the efficiencies of the previously described reduction techniques. These efficiency estimates could then be applied to the current baseline emissions data to calculate what emission levels could be reached. Lacking any other substantive data or technique at this time this methodology will be used.

The emission reduction efficiencies used in this analysis are those expected from the lower emitting engines in the current technology baseline (see Tables II-2 and II-3) so the average HC and CO emission rates from the low emitting engines will serve as the baseline levels. One might question the use of the lower emission levels as not being representative of the average emission levels. However for the higher emitting engines the efficiency estimates would in turn be substantially larger. We have chosen to use the lower emitting engines because they already reflect what could easily be achieved on other current technology engines with even minor calibration changes.

Tables II-2 and II-3 clearly indicate that the HC and CO emission levels in certain modes are so large that they require specific attention in this analysis. HC emissions could be divided into "cold/warm start" and "other." CO emissions could be divided into "LAF" and "other." Table II-6 lists the emission reduction techniques together with the modes in which they will be effective in gaining emission reductions. This information will serve as a background for the discussion which follows.

1. Hydrocarbons [3]

As shown in Table II-2 cold/warm start emissions account for 49 percent of the HC emissions. Thus the remaining 51 percent comes from the "other" six portions of the test. In terms of the average of the low emitting engines from Table II-3 the "cold/warm start" portions account for 0.92 g/BHP-hr and the "other" portions account for 0.96 g/BHP-hr.

With the emission control strategies shown in Table II-6 we believe that substantial reductions in HC emission levels are easily achievable. Our current belief is that reductions of 50-60 percent are possible in the "cold/warm start" portions of the test through the means shown in Table II-6. For all practical purposes "start" emissions are uncontrolled on the current test procedure. EPA also believes that reductions of 30-40 percent are also available on the other portions of the test procedure. Assuming the ranges of engineering estimates of reduction efficiencies given above, achievable emission levels can be calculated.

a. Cold/Warm Start Reductions

High Estimate: (0.92 g/BHP-hr)(60%) = 0.55 g/BHP-hr

Low Estimate: (0.92 g/BHP-hr)(50%) = 0.46 g/BHP-hr

New Range: 0.37 - 0.46 g/BHP-hr

b. Reductions in Other Portions

High Estimate: (0.96 g/BHP-hr)(40%) = 0.38 g/BHP-hr

Low Estimate: (0.96 g/BHP-hr)(30%) = 0.29 g/BHP-hr

New Range: 0.58 - 0.67 g/BHP-hr

c. Achievable Emission Levels

Using "High Estimate": 1.88 - 0.55 - 0.38 = 0.95 g/BHP-hr

Using "Low Estimate": 1.88 - 0.46 - 0.29 = 1.13 g/BHP-hr

Emission levels in the 0.95 - 1.13 g/BHP-hr range would support an HC emission standard of 1.3 g/BHP-hr.

Using a full life multiplicative deterioration factor of 1.2 and an HC variability of 10 percent, the expected target HC levels are 1.1 g/BHP-hr for 1984 (no SEA) and 1.0 g/BHP-hr when SEA begins in 1986. The range of achievable emission levels shown above supports the feasibility of these targets and thus the 1.3 g/BHP-hr standard.

2. Carbon Monoxide

As shown in Table II-3 the "LAF" (LA Freeway) CO emissions account for 43.2 percent of the total. Thus the remaining 56.8 percent arises from the "other" portions of the test. When these percentages are applied to the average low CO engines of Table II-3, the "LAF" accounts for 19.9 g/BHP-hr and the other portion accounts for 26.2 g/BHP-hr.

With the emission control strategies shown in Table II-6 substantial reductions in CO emission levels are easily achievable. Reductions of 40-50 percent are possible in the "LAF" portion of the test through the means in Table II-6. Emissions under the high-speed, high-power operation characteristic of the LAF portion are relatively uncontrolled because of the limited power demands of the 9-mode test procedure. Reductions of 30-40 percent are also possible from the "other" portions of the test procedure. Given the engineering estimates of reduction efficiencies shown above, achievable emission levels can be calculated.

a. LAF Reductions

High Estimate: (19.9 g/BHP-hr)(50%) = 10 g/BHP-hr

Low Estimate: (19.9 g/BHP-hr)(40%) = 8 g/BHP-hr

New Range: 9.9 - 11.9 g/BHP-hr

b. Reductions in Other Portions

High Estimate: (26.2 g/BHP-hr)(40%) = 10.5 g/BHP-hr

Low Estimate: (26.2 g/BHP-hr)(30%) = 7.9 g/BHP-hr

New Range: 15.7 - 18.3 g/BHP-hr

c. Achievable Emission Levels

Using "High Estimate": 46.1 - 10 - 10.5 = 25.6 g/BHP-hr

Using "Low Estimate": 46.1 - 8 - 7.9 = 30.2 g/BHP-hr

Emission levels in the 25.6 - 30.2 g/BHP-hr range would support a CO emission standard of about 35 g/BHP-hr. Using a full life multiplicative deterioration factor of 1.1 and a CO variability of 20 percent, the expected target CO levels are 31.8 g/BHP-hr for 1984 (no SEA) and 25.5 g/BHP-hr when SEA begins in 1986. The range of achievable emission levels shown above supports the feasibility of these targets and thus the 35 g/BHP-hr standard proposed here.

Considering all of the factors bearing on this analysis (cost, fuel economy, leadtime, power, and driveability), EPA believes that the standards herein discussed are achievable for all HDG engines for the 1984 model year. However if during the comment period further data and information would prove the standards to be infeasible the option for further relaxation for final rulemaking exists.

E. Idle Emission Standard

For heavy-duty gasoline engines, the 1984 idle CO standard is 0.47 percent (raw exhaust composition). Table II-7 presents the current technology idle CO baseline. Note that five of twelve engines already comply. Given the fact that substantial leaning of mixtures will be performed to meet the transient standards, there is no reason to believe the idle circuits of the remaining engines cannot be improved. EPA judges compliance with the idle standard to be relatively straightforward and will pose no problems to manufacturers even considering any small deterioration factor which may need to be included.

Table II-1

1979 HDG Current Technology Baseline

Engine	Family	HC* (g/BHP-hr)	CO* (g/BHP-hr)
Ford 400	6.6L "E"	4.89 (H)**	112.4 (H)
Chrysler 440	RBM	3.83 (H)	112.4 (H)
Ford 370	6.1L "E"	3.51 (H)	47.8 (L)
IHC 446	MV8	3.27 (H)	90.4 (H)
GM 350	113	3.14 (M)	118.1 (H)
Chrysler 360	LA1	2.67 (M)	96.1 (H)
GM 350	113	2.48 (M)	64.8 (M)
IHC 345	V345	2.44 (M)	34.4 (L)
GM 454	114	2.30 (M)	51.6 (L)
GM 366	114	2.16 (L)	43.4 (L)
GM 292	112	2.12 (L)	55.0 (L)
GM 454	115	1.31 (L)	78.5 (M)

* Average of several tests.

** Engines are classified as high (H), moderate (M), or lower (L) emitters of a given pollutant. Note that a high HC engine is also usually a high CO engine, but not in every case.

Table II-2

Engine by Engine Transient HC Emission Breakdown

		Cold Start				20 Minute Pause	Hot Start				Composite Test Result	High Medium, or Low Emitter[e]
		1 NYNF	2 LANF	3 LAF	4 NYNF		5 NYNF	6 LANF	7 LAF	8 NYNF		
	1[a]	24.73	17.11	15.10	5.55		9.66	11.14	12.53	5.71	-	
IHC 446	2[b]	23.26	6.97	1.81	5.23		10.65	4.61	1.50	5.36	3.32	H
	3[c]	.289	.188	.166	.061		.677	.736	.830	.373	3.32	
	4[d]	8.7%	5.6%	5.0%	1.8%		20.4%	22.2%	25.0%	11.2%	100%	
	1.	25.50	9.09	4.93	3.80		4.82	6.29	4.84	3.40	-	
IHC 345	2.	64.84	5.51	0.78	5.20		7.14	3.40	0.75	4.38	2.35	M
	3.	.40	.13	.07	.06		.44	.54	.42	.29	2.35	
	4.	17.0%	5.5%	3.0%	2.6%		18.7%	23.0%	17.9%	12.3%	100%	
	1.	47.86	12.73	5.95	2.61		4.96	4.89	5.07	2.62	-	
GM 366	2.	94.7	6.24	0.81	2.69		5.69	2.28	0.69	2.74	2.22	L
	3.	.64	.16	.08	.03		.39	.36	.37	.19	2.22	
	4.	28.8%	7.2%	3.6%	1.4%		17.6%	16.2%	16.7%	8.6%	100%	
	1.	61.49	12.57	6.42	2.81		4.71	6.50	4.56	2.74	-	
GM 350	2.	95.0	6.30	.92	3.06		5.56	3.16	.65	2.95	2.57	M
	3.	.86	.17	.08	.04		.37	.49	.35	.21	2.57	
	4.	33.5%	6.6%	3.1%	1.6%		14.4%	19.1%	13.6%	8.2%	100%	
	1.	32.91	16.16	14.67	6.68		8.62	10.11	13.17	5.69	-	
F 400	2.	46.77	9.66	2.60	9.38		12.10	5.77	2.33	8.02	4.80	H
	3.	.56	.26	.24	.11		.87	.96	1.25	.55	4.80	
	4.	11.7%	5.4%	5.0%	2.3%		18.1%	20.0%	26.0%	11.5%	-	
	1.	20.11	8.13	7.39	1.71		8.05	7.65	6.96	3.46	-	
F 370	2.	52.25	5.29	1.35	2.47		13.37	4.78	1.26	5.02	3.31	H
	3.	.36	.14	.13	.03		.85	.76	.69	.35	3.31	
	4.	10.9%	4.2%	3.9%	.9%		25.7%	23.0%	20.8%	10.6%	100%	

Table II-2 (cont'd)

Engine by Engine Transient HC Emission Breakdown

		Cold Start				20 Minute Pause	Hot Start				Composite Test Result	High Medium, or Low Emitter
		1 NYNF	2 LANF	3 LAF	4 NYNF		5 NYNF	6 LANF	7 LAF	8 NYNF		
	1.	8.56	7.18	8.22	3.63		10.23	6.41	7.87	3.52	-	
C 360	2.	13.11	3.42	1.08	3.96		13.54	2.99	1.04	3.77	2.45	M
	3.	.11	.09	.10	.05		.80	.47	.58	.28	2.45	
	4.	4.5%	3.6%	4.0%	2.0%		32.7%	19.2%	23.7%	10.2%	100%	
	1.	17.38	10.57	24.67	7.76		10.25	9.32	22.22	9.10	-	
C 440	2.	20.12	4.10	2.78	7.41		11.32	3.65	2.40	8.69	3.81	H
	3.	.19	.11	.26	.08		.67	.57	1.37	.56	3.81	
	4.	5.0%	2.9%	6.8%	2.1%		17.6%	15.0%	36.0%	14.7%	100%	
	1.	16.38	3.88	5.34	1.68		4.94	2.39	4.95	1.57	-	
GM 454	2.	19.06	1.74	.63	1.83		5.82	1.07	0.60	1.72	1.29	L
	3.	.20	.05	.06	.02		.35	.17	.33	.11	1.29	
	4.	15.5%	3.9%	4.7%	1.6%		27.1%	13.2%	25.6%	8.5%	100%	
	1.	47.31	4.33	2.08	1.64		4.12	3.71	1.95	1.83	-	
GM 292	2.	65.65	2.62	0.39	2.08		6.17	2.20	0.37	2.33	2.12	L
	3.	.80	.07	.03	.03		.43	.37	.20	.19	2.12	
	4.	37.7%	3.3%	1.4%	1.4%		20.3%	17.5%	9.4%	9.0%	100%	
	1.	44.54	15.43	6.80	6.43		11.65	6.97	5.65	5.80	-	
GM 454	2.	62.38	5.75	0.68	5.83		11.24	2.52	0.57	5.25	2.46	H
	3.	.44	.15	.06	.06		.70	.39	.33	.33	2.46	
	4.	17.9%	6.1%	2.4%	2.4%		28.5%	15.9%	13.4%	13.4%	100%	

Table II-2 (cont'd)

Engine [illegible]-Engine Transient HC Emission Breakdown

		Cold Start 1 NYNF	2 LANF	3 LAF	4 NYNF	20-Minute Pause	Hot Start 5 NYNF	6 LANF	7 LAF	8 NYNF	Total Test Composite	High Medium, or Low Emitter	Average HC Emission Level
GM 350	1.	21.04	6.13	10.39	3.69		3.66	5.01	9.51	3.71	-		
	2.	31.48	3.53	1.71	5.34		5.18	2.93	1.57	4.51	2.66	M	
	3.	.34	.09	.16	.06		.34	.46	.87	.34	2.66		
	4.	12.8%	3.4%	6.0%	2.3%		12.8%	17.3%	32.7%	12.8%	100%		
Average: All Engines	4.	17.0%	4.8%	4.1%	1.9%		21.1%	18.4%	21.7%	11.0%	100%	(12 engines)	2.76
Average: High HC Engines	4.	9.1%	4.5%	5.2%	1.8%		20.5%	20.1%	27.0%	12.0%	100%	H (4 engines)	3.81
Average: Med. HC Engines	4.	17.1%	5.0%	3.7%	2.2%		21.4%	18.9%	20.3%	11.4%	100%	M (5 engines)	2.50
Average: Low HC Engines	4.	27.3%	4.8%	3.2%	1.5%		21.7%	15.6%	17.2%	8.7%	100%	L (3 engines)	1.66

[a] Total grams per subcycle.
[b] Grams per brake-horsepower-hour per subcycle.
[c] Subcycle contribution, in effectively-weighted grams per brake-horsepower-hour, to the composite test result. (When added together, all subcycle contributions add up to the composite test result). For methodology, see Reference 1, pp. 4-5.
[d] Relative percentage of subcycle contribution (3) to the total composite test result.
[e] In grams per brake-horsepower-hour: High (H) > 3.3
3.3 > medium (M) > 2.3
Low (L) < 2.2

Table II-3

Engine-by-Engine Transient CO Emission Breakdown

		Cold Start				20-Minute Pause	Hot Start				Composite Test Result	High Medium, or Low Emitter[e]
		1 NYNF	2 LANF	3 LAF	4 NYNF		5 NYNF	6 LANF	7 LAF	8 NYNF		
	1[a]	236.4	245.2	774.8	127.2		123.3	200.0	708.1	122.7	-	
IHC 446	2[b]	222.4	99.9	93.0	119.9		135.9	82.7	84.7	115.1	92.88	H
	3[c]	2.79	2.73	8.63	1.42		8.73	13.3	47.1	8.20	92.88	
	4[d]	3.0%	2.9%	9.3%	1.5%		9.4%	14.3%	50.7%	8.8%	100%	
	1.	90.3	84.7	153.2	60.0		39.7	60.2	150.6	56.1	-	
IHC 345	2.	229.6	51.4	24.2	79.2		58.9	32.5	23.2	72.3	32.8	L
	3.	1.40	1.24	2.24	.88		3.70	5.29	13.11	4.94	32.8	
	4.	4.3%	3.8%	6.8%	2.7%		11.3%	16.1%	40.0%	15.1%	100%	
	1.	143.7	140.7	187.7	86.1		88.0	113.3	167.0	88.2	-	
GM 366	2.	284.3	69.1	25.5	88.8		100.8	52.9	22.8	92.1	41.9	L
	3.	1.9	1.8	2.4	1.1		6.9	8.7	12.5	6.6	41.9	
	4.	4.5%	4.3%	5.7%	2.6%		16.5%	20.8%	29.8%	15.8%	100%	
	1.	171.2	155.2	404.5	102.6		111.6	130.2	376.6	95.3	-	
GM 350	2.	264.5	77.7	57.8	116.6		131.9	63.4	53.9	102.5	67.8	M
	3.	2.4	2.1	5.3	1.4		9.3	10.1	29.7	7.4	67.8	
	4.	3.5%	3.1%	7.8%	2.1%		13.7%	14.9%	43.8%	10.9%	100%	
	1.	222.9	162.4	620.6	130.6		103.5	161.6	582.3	127.3	-	
F 400	2.	316.7	97.0	109.9	183.5		145.4	92.2	103.0	179.6	113.2	H
	3.	3.8	2.6	10.0	2.1		10.6	15.6	56.2	12.3	113.2	
	4.	3.4%	2.3%	8.8%	1.9%		9.4%	13.8%	49.6%	10.9%	100%	
	1.	85.2	106.6	230.7	21.4		38.8	80.1	206.7	40.3	-	
F 370	2.	221.5	69.4	42.1	30.9		64.4	50.0	37.4	58.4	45.0	L
	3.	1.5	1.8	3.9	.4		4.2	8.1	21.0	4.1	45.0	
	4.	3.3%	4.0%	8.7%	.9%		9.3%	18.0%	46.7%	9.1%	100%	

Table II-3 (cont'd)

Engine-by-Engine Transient CO Emission Breakdown

		Cold Start				20-Minute Pause	Hot Start				Composite Test Result	High Medium, or Low Emitter
		1 NYNF	2 LANF	3 LAF	4 NYNF		5 NYNF	6 LANF	7 LAF	8 NYNF		
C 360	1.	107.5	144.7	868.6	61.2		56.6	127.9	783.0	58.5	-	
	2.	164.7	68.8	113.8	66.7		76.3	59.5	103.3	62.6	92.0	H
	3.	1.4	1.8	10.8	.8		4.6	9.6	58.6	4.4	92.0	
	4.	1.5%	2.0%	11.7%	.9%		5.0%	10.4%	63.7%	4.8%	100%	
C 440	1.	228.3	203.6	1262.0	100.6		75.2	161.1	1217.2	94.1	-	
	2.	264.3	78.9	142.1	96.0		83.0	63.0	131.7	89.9	115.6	H
	3.	2.5	2.1	13.1	1.0		5.0	10.0	75.9	5.9	115.6	
	4.	2.2%	1.8%	11.3%	.9%		4.3%	8.7%	65.7%	5.1%	-	
GM 454 (Short Block)	1.	250.3	86.2	769.6	65.2		86.9	102.8	714.1	69.7	-	
	2.	291.3	38.7	91.3	71.1		102.4	45.8	87.2	76.2	81.9	M
	3.	3.1	1.0	9.0	.8		6.4	7.2	49.5	4.9	81.9	
	4.	3.8%	1.2%	11.0%	1.0%		7.8%	8.8%	60.4%	6.0%	100%	
GM 292	1.	315.0	115.7	159.4	64.7		89.4	111.0	161.5	70.0	-	
	2.	437.1	69.9	30.2	81.9		133.7	65.9	30.5	89.1	55.0	L
	3.	5.6	2.0	2.7	1.1		9.6	11.2	16.3	7.1	55.0	
	4.	10.2%	3.6%	4.9%	2.0%		17.5%	20.4%	29.6%	12.9%	100%	
GM 454 (Tall Block)	1.	204.8	175.6	376.1	144.6		153.9	157.1	366.2	138.2	-	
	2.	286.9	65.5	37.9	131.1		146.1	56.7	36.9	124.9	55.9	L
	3.	2.1	1.7	3.6	1.4		9.3	9.0	20.9	7.9	55.9	
	4.	3.8%	3.0%	6.4%	2.5%		16.7%	16.1%	37.4%	14.1%	100%	

Table II-3 (cont'd)

Engine-by-Engine Transient CO Emission Breakdown

		Cold Start 1 NYNF	2 LANF	3 LAF	4 NYNF	20-Minute Pause	Hot Start 5 NYNF	6 LANF	7 LAF	8 NYNF	Total Test Composite	High Medium, or Low Emitter	Average HC Emission Level
GM 350	1.	196.1	108.9	805.5	68.1		92.1	104.8	640.8	64.8	-		
	2.	293.3	62.6	132.21	98.6		130.1	61.4	106.0	78.8	101.5	H	
	3.	3.2	1.7	12.1	1.1		8.5	9.7	59.2	6.0	101.5		
	4.	3.2%	1.7%	11.8%	1.1%		8.4%	9.6%	58.3%	5.9%	100%		
Average All Engines	4.	3.9%	2.8%	9.5%	1.7%		10.7%	14.2%	47.9%	9.9%	100%	(12 engines)	75.7
Average High CO Engines	4.	2.6%	2.1%	12.6%	1.2%		7.1%	11.1%	56.3%	7.0%	100%	(5 engines)	105.5
Average Mod CO Engines	4.	3.7%	2.2%	9.4%	1.6%		10.8%	11.9%	52.1%	8.5%	100%	(2 engines)	74.9
Average Low CO Engines	4.	5.2%	3.7%	6.5%	2.1%		14.3%	18.3%	36.7%	13.4%	100%	(5 engines)	46.1

[a] Total grams per subcycle.
[b] Grams per brake-horsepower-hour per subcycle.
[c] Subcycle contribution, in effectively-weighted grams per brake-horsepower-hour, to the composite test result. (When added together, all subcycle contributions add up to the composite test result). For methodology, see Reference 1, pp. 4-5.
[d] Relative percentage of subcycle contribution (3) to the total composite test result.
[e] In grams per brake-horsepower-hour: High (H) > 90
90 ≥ medium (M) ≥ 60
Low (L) < 60

Table II-4

9-Mode Versus Transient Emissions

Current Technology Engines[1][2]

Engine	BSHC		BSCO	
	9-Mode	Transient	9-Mode	Transient
1979 GM 292	0.42	2.12	26.86	54.98
1979 GM 454	0.39	2.30	17.33	51.55
1979 GM 350	0.79	3.14	14.62	118.07
1979 IHC 446	0.42	3.27	24.28	90.40
1979 GM 366	0.50	2.16	17.40	43.43
1979 IHC 345	2.73	2.44	17.68	34.44
1979 GM 350	0.59	2.48	20.40	64.76
1979 Ford 400	2.15	4.89	53.16	112.43
1979 Ford 370	1.20	3.51	37.12	47.75
1979 Chrysler 360	1.18	2.67	21.38	98.14
1979 Chrysler 440	0.83	3.83	10.47	112.38
1979 GM 454	0.47	1.31	20.11	78.49

[1] Engines were tested as received from the manufacturers.

[2] All levels are undeteriorated.

Table II-5

Cold Start Contribution to Composite Emission Results

Engine	HC Composite HS	HC Composite Total Test	HC % Due To CS	CO Composite HS	CO Composite Total Test	CO % Due To CS
Ford 400	4.26	4.80(H)	11.3%	110.4	113.2	2.5%
Chrysler 440	3.70	3.81(H)	2.9%	112.5	115.6	2.7%
Ford 370	3.10	3.31(H)	6.3%	43.5	45.0	3.3%
IHC 446	3.06	3.32(M)	7.8%	90.5	92.9	2.6%
GM 350	1.71	2.57(M)	33.5%	66.0	67.8	2.7%
Chrysler 360	2.46	2.45(M)	neg.	90.0	92.0	2.2%
GM 350	2.36	2.66(M)	11.3%	97.2	101.5	4.2%
IHC 345	1.98	2.35(M)	15.7%	31.3	32.8	4.6%
GM 454	1.14	1.29(L)	11.6%	79.8	81.9	2.6%
GM 366	1.55	2.22(L)	30.2%	40.4	41.9	3.6%
GM 292	1.38	2.12(L)	34.9%	51.2	55.0	6.9%
GM 454	2.04	2.46(M)	17.1%	54.8	55.9	2.0%

HC Averages: High (H): 6.3%
Med. (M): 14.2%
Low (L): 25.6%

* Grams/BHP-hr, results of individual tests, unweighted.

Table II-6

Test Portions/Emission Reduction Technologies

	HC		CO	
	Cold/Warm Start[1]	Other[2]	LAF[3]	Other[4]
Carburetion	X	X	X	X
Calibrations	X	X	X	X
Manifold/Combustion Chamber	X	X	X	X
Air Injection		X	X	X
Automatic Choke	X			X
EFE	X			X
Heated Air Intake	X			X
EGR		X		

[1] Sample Bags 1 & 5

[2] Sample Bags 2, 3, 4, 6, 7, 8

[3] Sample Bags 3 & 4

[4] Sample Bags 1, 2, 4, 5, 6, 8

Table II-7

Idle CO Current Technology Baseline Emissions

Engine	Idle CO (%)	Complies with 1984 standard?
IHC 446	.299	yes
IHC 345	.402	yes
GM 366	.913	no
GM 350	1.158	no
Ford 400	1.853	no
Ford 370	.515	no
Chrysler 360	.226	yes
Chysler 440	1.279	no
GM 454	.596	no
GM 292	.308	yes
GM 454	.888	no
GM 350	.242	yes

Figure II-1

CO Distribution of 1979 Baseline Engines

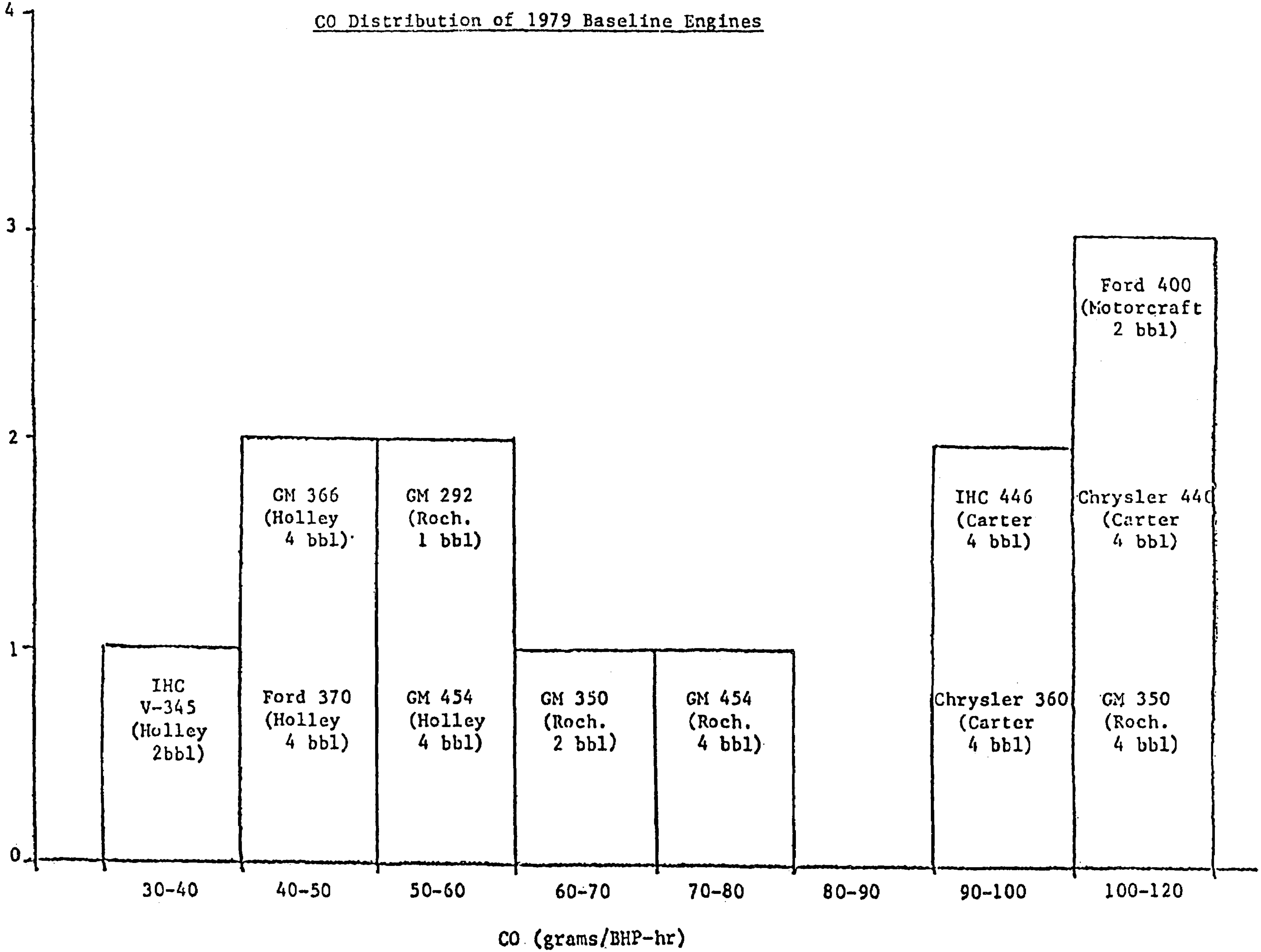
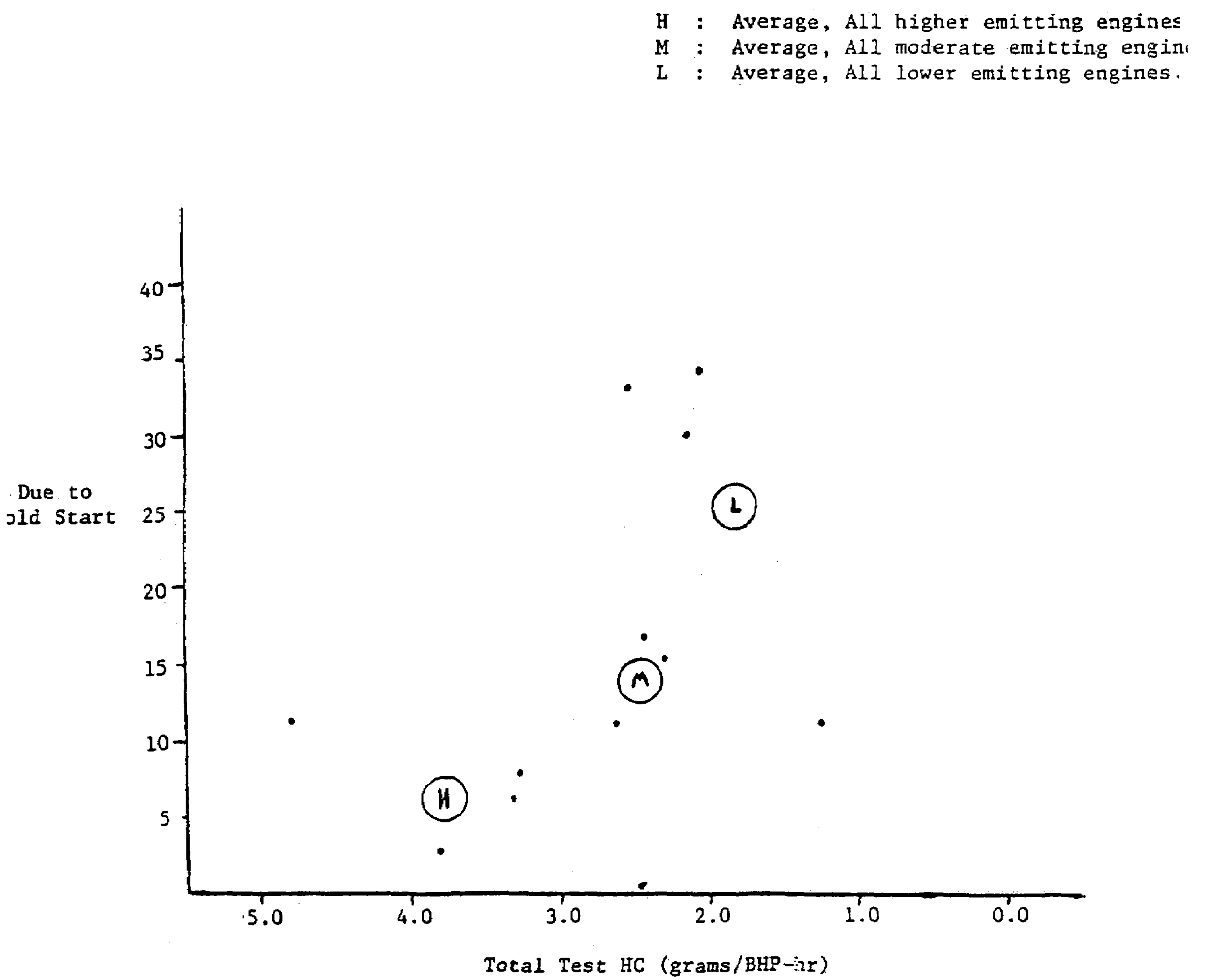


Figure II-2

Cold Start Contribution to Total Test
HC Emissions as a Function of Total Test Emissions



References

1. Cox, Timothy P., "Heavy-Duty Gasoline Engine Emission Sensitivity to Variations in the 1984 Federal Test Cycle," SAE No. 801370.

2. Auiler, J., et. al., "Optimization of Automotive Engine Calibration for Better Fuel Economy-Methods and Applications," SAE Paper No. 770076.

3. Here we are addressing total hydrocarbon emissions and a total hydrocarbon emission standard. EPA intends to propose an optional non-methane hydrocarbon standard for HDEs in a future rulemaking.

4. The terms "High Estimate" and "Low Estimate" refer to the range of reduction efficiencies. The percent figures shown are the actual efficiencies.

The Transient Test Study: A Review of the 1984 Heavy-Duty Engine Testing Requirements

An ECTD Staff Report

June 1982

Appendix B

The Transient Test Study

Table of Contents

CHAPTER 1

EXECUTIVE SUMMARY

As part of EPA's efforts at regulatory relief, this study reexamines transient testing requirements for 1984 and later model year heavy-duty engines, and recommends changes where necessary. This study addresses economic issues (e.g., testing costs, available leadtime, test implementation dates) and technical issues (e.g., alternative test cycles). This document will serve as a reference for the upcoming revised 1984 gaseous emission regulations for heavy-duty engines, in which the specific changes recommended by this study will be promulgated.

Chapter 2 presents an overview of the study, a brief history of the transient test procedure and associated issues, and enumerates the specific issues addressed by the study. In particular, the issues addressed within are: 1) economic impact of the transient test, and the possibilities for relief, 2) the technical adequacy of EPA's test cycles, 3) the acceptability and implementation options for the industry's proposed alternative test cycles, and 4) the steady-state option for heavy-duty diesel engines. Specific technical modifications to the test procedure will be addressed later in the revised 1984 gaseous emission regulations for heavy-duty engines.

Chapter 3 reviews the economic impact, facility status, and leadtime requirements associated with running the transient test procedure. As of November 1981, the majority of facility expenditures had been made; these investments are unrecoverable if the transient test is delayed or withdrawn. As a result, most manufacturers support the retention of a transient test. Leadtime requirements, however, indicate that some relief is necessary in 1984, i.e., steady-state testing or carryover on the steady-state test in conjunction with optional certification on the transient test. International Harvester (gasoline) currently plans to leave the gasoline engine market the year the transient test becomes effective; a single year deferral will ease its withdrawal. Chrysler has refused to make investments in both transient facilities and engine development work to meet stricter standards, thereby allowing itself to be driven from the market when the new requirements become effective. There is no fair administrative way, however, by which EPA can provide relief to Chrysler alone on what is essentially its business decis-.n

Chapter 4 reviews the more recent criticisms of EPA's specific gasoline and diesel test cycles. The criticism applies to the representativeness of the test cycles and operational problems associated with actually running the test. A.D. Little Inc.'s Report to the MVMA, harshly critical of EPA's methodology, is reviewed. (EPA's comprehensive analysis of the A.D. Little Report is attached as Appendix IV.) EPA finds no reason to conclude that the EPA cycles or test are unrepresentative. The industry criticism is almost entirely speculative with no emission evidence for substantiation. All recent emission data (including emission correlation of EPA's cycles with the alternative cycles proposed by the industry) continue to confirm the acceptability of EPA's test, both in construction and in operation.

Chapters 5 and 6 review the alternative test cycles developed and proposed by the EMA and MVMA. In general, the cycles are statistically similar despite the fact that they were developed using different methodologies. With respect to emissions, they correlate well with EPA's cycles; absolute emission levels measured over the alternate cycles are less (especially for HC) than those measured on EPA's cycles. In fact, at a given numerical standard the alternate cycles are less stringent; adoption of the alternate cycles without adjusting the EPA cycle-based standards represents a relaxation of emission standards by test procedure change. More comparative testing between the EPA and MVMA cycles may be necessary, due to the small existing data base and unresolved technical concerns about the MVMA cycle.

Chapter 7 addresses the issues surrounding the diesel engine transient test and the 13-mode option. Based upon leadtime considerations, a single model year deferral for 1984 appears necessary. The latest 13-mode versus transient data indicate that the steady-state test is indeed a poor predictor of transient emissions. With respect to emission control, there is little difference between optional steady-state HC standards of 0.5 g/BHP-hr and 1.3 g/BHP-hr; a single year deferral is recommended simply to provide maximum flexibility to the industry as they spread transient certification over two model years. Also reviewed is the option of allowing continued carryover of steady-state data for several years until recertification is required. This option would likely defer almost all transient testing. It would also preclude HC emission reductions made possible by the transient test, in spite of the substantial investments already made by the industry for transient test facilities. This degree of relief is unnecessary and unjustified.

Chapter 8 summarizes the conclusions of the study and makes the following recommendations:

1. Finalize the transient test for 1985; allow its use as an option in 1984. Allow gasoline and diesel engine manufacturers to carryover 1983 steady-state data (1979 standards and regulations) for 1984. After 1984, all certification testing will be based upon the transient test.

2. Allow the use of the EMA and MVMA alternative test cycles as options, certifiable to optional emission standards which are equivalently stringent to EPA cycle-based standards. (Note that these alternative cycle standards may change, especially for the MVMA cycle, as the comparative data base is increased.) Eventually select single cycles and standards.

3. Finalize necessary technical amendments to the test procedure in the upcoming revised 1984 gaseous emission regulations, to minimize both cost and complexity.

4. Continue cooperation with the heavy-duty engine industry to establish correlation between laboratories and to refine the transient test procedure as necessary.

These recommendations provide the needed relief to the industry; the environmental impacts of these recommendations are expected to be minimal.

CHAPTER 2

INTRODUCTION

I. Overview

As part of its commitment to regulatory relief, EPA initiated this study to review the mandatory 1984 heavy-duty engine certification test procedure. Specifically, the study is intended to determine if there is a need to revise transient testing requirements. Information used in the study was solicited directly from the manufacturers in a separate Federal Register notice (Appendix I) and as part of a Notice of Proposed Rulemaking for Revised Gaseous Emission Regulations for 1984 and Later Model Year Heavy-Duty Engines (Appendix II). This study will serve as a reference document for that upcoming final rulemaking. In particular, it will serve as a large part of the Summary and Analysis of Comments pertaining to the test procedure. The recommendations for revisions to testing requirements contained within this report will be incorporated into that final rulemaking.

II. The History of the Transient Test Procedure

The transient test procedure for heavy-duty engines is not a recent phenomenon; its origins lie at the beginning of the effort to control air pollution from mobile sources.

As early as 1967, studies indicated that steady-state emission tests were unrepresentative of on-road truck emissions.* Based upon this and light-duty experience,** EPA began the development of a more representative heavy-duty engine test procedure in 1972. (This was the same year in which the Federal transient emission test became effective for light-duty vehicles.) Following studies which developed a sampling plan for New York City and Los Angeles trucks, an on-road truck operational study (the CAPE-21 Project) was initiated in late 1973 under joint management by EPA and the industry-staffed Coordinating Research Council. The New York and Los Angeles phases of the project were completed by May of 1975. (Note that the data collection methodologies were derived by both the industry and EPA.) Editing of this on-road data and computer generation of the test cycles***

* See Appendix III for a complete listing of pertinent technical reports and references.

** The original LDV emission test was the California 7-mode, a steady-state test, and was used through 1971. The modal test was found to be inadequate, especially when emission control technology was applied to meet it, and it was replaced in 1972 by the transient CVS-72 procedure.

*** See Chapter 4 of this study.

began immediately, followed by selection of the final test cycles in November of 1977. During this time EPA also evaluated testing methods (engine vs. chassis dynamometer testing) and emissions sampling methodologies to develop the accompanying test procedure. The Draft Recommended Practice for the new test procedure was published in August of 1978.

The Clean Air Act Amendments of 1977 directed EPA to conduct uncontrolled HC and CO baseline studies to derive emission standards for the 1983 model year. EPA began baseline testing of 1969 model year engines using the new test procedure in February of 1978; EPA's contractor (the Southwest Research Institute in San Antonio, Texas) also began gasoline engine transient testing in June of 1978. Following this testing, the resulting emission standards and the new transient test procedure were proposed in February of 1979 and promulgated the following December. During and after this time period, EPA conducted extensive transient testing projects, including 1969, 1972/73, current technology, and prototype gasoline engine baselines, and current technology diesel engine baselines.

The manufacturers raised several issues in response to the proposed rulemaking of February 1979: 1) EPA's technical justification for a transient test, 2) the representativeness of EPA's test cycles, 3) the lack of validation of the test procedure, 4) the availability of test procedure alternatives, 5) the industry's lack of transient experience and its inability to comment meaningfully, 6) the technical adequacy of the overall test procedure, 7) alternative test cycles for eddy current dynamometers, and 8) technical details of the procedure. The original Summary and Analysis of Comments to the NPRM dealt at length with all of these issues; the analysis strongly defended EPA's original proposal, although several changes to the test procedure were made and a single year steady-state option was given to the diesel engine industry.

Since promulgation of the test procedure, the industry has continued to raise concerns about the transient test. As part of EPA's recent efforts to provide regulatory relief, the Agency solicited manufacturers for information on June 17, 1981, (46 FR 31677);* this information pertained to leadtime, economic impact, transient versus steady-state emissions, and technical problems associated with the new test procedure. EPA then reopened the entire transient test issue for comment on January 13, 1982, (47 FR 1642), as part of the NPRM for Revised Gaseous Emission Regulations for 1984 and Later Model Year Light-Duty Trucks and Heavy-Duty Engines.** The last period for submitting information and comment on the transient test procedure closed April 12, 1982.

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* See Appendix I, and Public Docket No. A-81-20.

** See Appendix II, and Public Docket No. A-81-11.

III. Outstanding Issues

The major test procedure issues raised by the manufacturers since the transient test's original promulgation are easily grouped into five separate categories: 1) economic impact, 2) the validity of EPA's test (in concept and in operation), 3) proposed alternative test cycles, 4) technical amendments to the test procedure, and 5) issues surrounding a transient test for heavy-duty diesel engines/optional 13-mode standard.

A. Economic Impact (Chapter 3)

Almost all comments received in this area described the capital expenditures which have been invested in transient facilities, and the leadtime required to complete these facilities. The comments were not in great detail or length, and all were provided in response to the June 17, 1981, Federal Register Notice. Aside from facility expenditures, no manufacturer addressed incremental development costs (to design engines to meet transient standards), or aggregate costs associated with actually running the test. (Some manufacturers did, however, identify specific technical amendments to the test procedure which would yield cost savings. See below.)

B. *The Validity of EPA's Test (Chapter 4)*

In most cases, the industry reiterated its concerns with the representativeness of EPA's test cycles, and problems associated with actually running the test. Doubts about the validity of EPA's cycle were directed mainly at the cycle development methodology and the CAPE-21 data base. The criticism was similar to that made over the last several years. With respect to running a transient test, the industry is concerned with potential repeatability and correlation problems, and its inherent jeopardy if such problems arise during confirmatory or SEA testing.

B. Alternative Test Cycles (Chapters 5 and 6)

The Engine Manufacturers' Association (EMA) and the Motor Vehicle Manufacturers' Association (MVMA) both proposed that EPA adopt their specific alternative test cycles, as an option or in lieu of EPA's test cycles. The major issues associated with these test cycles are their technical acceptability, their relative stringency, and how - if at all - they should be implemented.

D. Technical Amendments to the Test Procedure

The industry, in particular the EMA, has suggested numerous technical amendments to the procedure to reduce cost and complexity, and enhance technical aspects of the test.

These suggestions range from recommended elimination of the cold start requirements to modification of more routine aspects of the test (e.g. sampling system calibration procedures).

These recommended changes are perhaps as important in reducing the economic impacts of the transient test as any other possible action. They do not, however, materially affect the overall implementation decisions associated with the transient test. For this reason, they will not be specifically addressed in this study, but in the separate Summary and Analysis of Comments document to be published with the revised HD 1984 gaseous emission regulations. We intend to make as many technical and test efficiency improvements as possible, using the comments and accumulated experience of both the industry and EPA.

E. Diesel Transient Test/13-Mode Option (Chapter 7)

Some diesel manufacturers have questioned the need for a transient test, especially for the small increments of HC emission reductions required for diesel engines for 1984-86. They have argued that the 13-mode would be adequate to ensure that mandated HC emission reductions would in fact take place. Use of the transient test would, in their judgment, be an expensive overkill of the problem. All diesel manufacturers have invested in transient testing facilities, but all support a more extensive and less stringent 13-mode option than the one EPA has already provided.

IV. Issues Not Addressed

A few issues are not addressed in this study. The technical justification for a transient test for gasoline engines was not challenged by the manufacturers; EPA's original analysis stands firm.* In addition, steady-state tests are poor predictors of transient emissions for gasoline engines: there is no means by which a steady-state test can adequately represent actual gasoline engine operating characteristics and be equivalently stringent to the transient. This removes any possibility of providing a technically acceptable steady-state option for gasoline engines. Finally, no diesel engine manufacturers have pursued the use of eddy current dynamometers for transient testing, and their acceptability need not be addressed.

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* See EPA's earlier analysis of this issue in Chapter 1 of the Summary and Analysis of Comments to the NPRM: "1983 and Later Model Year Heavy-Duty Engines - Proposed Emission Regulations," December 1979.

CHAPTER 3

ECONOMIC IMPACTS, LEADTIME, AND FACILITY STATUS

I. Overview

Manufacturers of heavy-duty gasoline and diesel engines have been concerned about the cost and leadtime for transient test facility development since the transient test was first proposed in February of 1979. Most manufacturers have indicated that economic factors and leadtimes have not been sufficient for engine development and certification on the transient test for 1984. Regulatory relief is intended to decrease the economic burden of implementing regulations on the manufacturers. In this chapter the economic impacts, facility status, and leadtimes associated with the manufacturer's capability to perform transient engine tests and their effects on regulatory relief efforts will be discussed.

II. Summary of Comments[1,2]

Comments have been received from nine manufacturers regarding the status and the economic impact of developing transient test capabilities. The facility requirements, estimated costs, capital committed, and possible deferred expenditures are summarized on a manufacturer-by-manufacturer basis in Table 3-1. The manufacturers also provided projections of available leadtimes, and their estimates of when certification on the transient test will be feasible. These projections are summarized in Table 3-2. Comments concerning manufacturer's individual situations and recommendations are summarized below.

A. Caterpillar

As of 11/1/81 Caterpillar had spent $10.1M of an estimated $12.9M necessary for transient test facilities. Caterpillar stated that 10 transient test cells would be required for development and certification of 13 engine families for model years 1984-85. Caterpillar is opposed to any delay in the implementation of a properly structured transient test for Federal certification in 1984 for two reasons:

1. Caterpillar has already invested significant resources to develop transient test capabilities, and this investment cannot be retrieved if the transient testing is delayed; and,

2. The California Air Resources Board (CARB) has adopted optional transient standards for 1984 which Caterpillar feels are more reasonable than CARB's steady-state standards. Caterpillar opposes any EPA action which may force CARB to withdraw its transient standards.

Table 3-1

Manufacturers' Economic Impact of Developing Transient Test Capabilities

Manufacturer	Test Cells Completed	Test Cells Required	Estimated Facility Costs[1]	Already Committed[1]	Possible Deferred Expenditures[1]
Caterpillar	4	10	$12.9M	$10.1M (78%)	$2.8M (22%)
Chrysler	0	2	$1.9M	$0.0M (0%)	$1.9M (100%)
Cummins	2	12	$8.1M	$6.3M (78%)	$1.8M (22%)
Daimler-Benz	1	3	$5.8M	$3.8M (66%)	$2.0M (34%)
Ford	4	4	$6.0M	$6.0M (100%)	- (0%)
General Motors					
(gas)	4	4	$3.0M	$3.0M (100%)	- (0%)
(diesel)	1	12	$18.0M	$13.0M (72%)	$5.0M (28%)
Hino	0	1	$2.2M	$2.2M (100%	- (0%)
International Harvester					
(gas)	0	4	$2.0M[2]	$0.0M (0%)[2]	$0.0M (0%)[2]
(diesel)	1	2	$5.7M	$2.1M (37%)	$3.6M (63%)
Mack	2	6	$5.0M	$1.0M (20%)	$4.0M (80%)
TOTAL COST			$68.6M	$47.5M (69%)	$21.1M (31%)

[1] 1981 dollars.
[2] IHC plans to leave the gasoline engine market before the transient test is mandatory. IHC's estimated costs for gasoline facilities therefore are not included in the Total Cost or Possible Deferred Expenditures.

Table 3-2

Model Year for Availability of Transient
Test Facilities for Certification of All Engine Families

Manufacturer	Model Year - Gas	Model Year - Diesel
Caterpillar	NA	1985
Chrysler	1986*	NA
Cummins	NA	1985
Daimler-Benz	NA	1984
Ford	1984	NA
General Motors	1984	1985
Hino	NA	1984
International Harvester	NA**	1984
Mack	NA	1984

* Dependent on Chrysler decision to acquire its own test facilities.

** IH will abandon the gasoline engine market when transient tests are required for certification.

Although Caterpillar stated it was opposed to any delay in the implementation of the transient test for 1984 certification, it also indicated that the leadtime for facility development is not sufficient for certification of all of their 1984 engines on the transient test, and some families will require carryover on the optional steady-state standards. Caterpillar recommends the optional steady-state standard be revised to 1.0 g/bhp-hr. This would allow more of Caterpillar's engines to qualify for carryover and would result in a more orderly phase-in of the transient test.

B. Chrysler

Chrysler has not invested any money to develop its transient test capability and estimates it would require $1.9M and two years to do so. Because of the small projected sales volume of heavy-duty gasoline engines and its need to use all available capital for passenger car development, Chrysler decided to abandon this market segment when the transient cycle regulation was promulgated. Unless an alternative to the transient cycle is offered, Chrysler feels it must either buy certified engines from other manufacturers or pay an outside engineering service to develop Chrysler engines to comply with the transient test standards. Chrysler fears either of these approaches would make the prices of its heavy-duty vehicles uncompetitive.

The possibility also exists that Chrysler Corporation will offer diesel engines for heavy-duty trucks for the 1984 model year. These engines will be purchased and responsibility for all emission testing will rest with the engine supplier.

Chrysler requests a steady-state test be allowed as an option, at least for smaller manufacturers, for model years 1984 through 1987. This would allow Chrysler to continue production of heavy-duty gasoline engines.

C. Cummins

Cummins has committed $6.3M of an estimated $8.1M necessary for transient test facility development. Cummins stated that it would have two transient test cells operational by January 1982. Cummins also indicated that it would need 10 transient test cells in the beginning of 1983 and would need 12 transient test cells by the end of 1983. Their present planning indicates that only 8 cells will be available at the beginning of 1983, and 4 additional test cells, for a total of 12, will become available for use at the end of 1983. Cummins said that the lack of test facilities would prevent it from certifying all of its engine families to a 1.3 HC standard for the 1984 model year. Cummins recommends the option of certification on either the steady-state test or the transient test until the new NOx and particulate standards take effect. After this, it recommends only the transient test be used.

D. Daimler-Benz

Daimler-Benz has committed $3.84M and requires an additional $1.8M-$2.0M for the development of three transient test cells. Daimler-Benz facility development is behind schedule, but it did not claim that it would be unable to certify its four 1984 model year engine families on the transient test. Daimler-Benz recommends allowing the 13-mode test with a 1.1 g/BHP-hr HC standard as an option through the 1985 model year.

E. Ford

Ford has already committed all of its required $6.0M for transient testing facilities (including four double-ended dynamometers) for certification of three 1984 heavy-duty gasoline engine families. Ford indicates that none of this investment is recoverable if the transient test is delayed or cancelled. However, Ford recommends delay of implementation of the transient test because:

1. There is insufficient leadtime to conduct an orderly development and certification of engines for 1984,

2. A delay would be beneficial in terms of gaining additional experience with the new test cycle and engine calibrations, and

3. A delay would enable a laboratory-to-laboratory correlation program to be conducted.

E. General Motors

General Motors has spent $16.0M of an estimated $21.0M toward the construction and development of transient test facilities. GM stated that four gasoline engine transient test cells have been completed and another is under construction. These five cells will be adequate for certification testing of all of its gasoline engine families for the 1984 model year if the standards will not require development testing. However, additional leadtime is necessary to comply with the proposed standards. GM, also indicated the conversion of test cells from 9-mode to transient test capability will not allow it to certify on the 9-mode test in 1984.

One test cell for diesel engine testing is complete, but GM requires twelve diesel test cells. GM will not have sufficient facilities for transient test certification of diesel engines until the 1985 model year. Also, due to the test cell conversions, 13-mode facilities will not be adequate to allow certification testing of all of its 1984 model year diesel engine families. Therefore, GM is requesting that EPA allow carryover for the 1984 model year and allow the transient test to be used as an option.

GM's recommendations for both gasoline and diesel engine certification are:

1. Allow carryover of current certification procedures and emission standards through 1984, but also allow the option of the transient test for 1984. This will allow GM to certify new engines, first introduced in 1984, on the transient test. Previously certified engines, which are carried over in 1984, would be tested on the transient procedure in 1985. Since the new engines tested on the transient procedure in 1984 would qualify for carryover in 1985, this plan would spread the burden on GM's test facilities over a two-year period.

2. Allow the option of either the transient test or the steady-state test with emission standards of equivalent stringency as the transient test for 1985 and 1986. This recommendation is entirely for manufacturers who may still be unable to certify on the transient test for these years. GM has explicitly stated that it does not require this action itself.

3. Beginning in 1987, use only the transient test.

F. Hino

Hino is planning investment of $2.2M for transient certification test facilities. Hino plans to certify two engine families and only need one transient test cell if implementation of SEA is delayed. Hino anticipated completing this transient test cell at the end of 1983. Hino recommends "adoption of the steady-state test as an optional method of certification for 1984 and after."

G. International Harvester

International Harvester has invested $2.1M of an estimated $5.7M required for heavy-duty diesel engine transient testing facilities and has cancelled investment of S2.0M for gasoline engine transient testing facilities

IHC indicated that the dramatic shift in the market from gasoline engines to diesel engines will force them out of the gasoline engine market. IHC indicates that the major factor in leaving the market is simply the market change, but the implementation date of the transient test will influence when this takes place. IHC has indicated that a single year deferral (until 1985) of transient testing requirements will allow it to withdraw from the market in a more orderly fashion.

IHC recommends delaying the implementation of the transient test for diesel engines until the time the new NOx and particulate standards take effect. IHC's recommendation is mainly based on a desire to develop control technology to meet all four regulated pollutant levels at the same time. IHC did not provide EPA with any information to indicate that 1984 model year diesel engine certification would be delayed due to test facility problems.

H. Mack

Mack has invested $1.0M of an estimated $5.0M required to develop transient testing capability. Mack has completed two transient test cells out of a planned total of six. Because of the depressed and unanticipated economic condition of the industry, Mack has decided to defer a decision on the development of the rest of its facilities until the end of 1982. Mack stated that the two transient test cells now completed are sufficient to certify all of its 1984 engine familes to a 1.3 HC standard.

Mack recommends delaying transient test requirements until the new particulate standards become effective, and using the 13-mode steady-state test with emission standards of equivalent stringency as the transient test for certification until that time.

III. Analysis of Comments

Manufacturers of heavy-duty gasoline and diesel engines have collectively committed $47.5M, or 69 percent of a total $68.6M required for transient testing facilities. These costs are higher than those projected earlier by EPA,[3,4] but we do not challenge the manufacturers' estimates for money which has already been spent. It is universally argued by the industry that most of these sunk costs cannot be recovered if the transient test is withdrawn or delayed. If the transient test implementation is delayed, investment of $21.1M industry-wide, or 31 percent of the total could be deferred for approximately the same period of time as the delay. For the most part, the outstanding transient test issues involve the technical and timing aspects rather than the need for additional expenditures. The leadtime for engine development is also an important issue.

The transient test is, however, more of an economic issue for two manufacturers which have been more severely impacted by the recent economic conditions and which have experienced the greatest difficulty in amortizing investments because of smaller production volumes. These companies are Chrysler and International Harvester. These two manufacturers claim that they have delayed investment in transient test facilities out of financial necessity, although no economic data were submitted to substantiate these difficulties. (This was true for all manufacturers.) A delay in transient test implementation would allow Chrysler to continue production of gasoline engines. (IHC will phase out gasoline engines by 1985. After 1984, IHC will be unaffected by any test procedural change).

Table 3-2 summarizes the manufacturers' comments regarding the model year that sufficient transient test facilities would be available for certification of <u>all</u> engine families. Except for Chrysler's and International Harvester's gasoline engines, all manufacturers will have transient test facilities to certify some, if not all, of their engine families in 1984.

Chrysler's cancellation of investment in transient test facilities and intention to abandon the gasoline engine market when the transient test becomes mandatory have been business decisions based on what it perceives to be low profitability of this portion of its product line. Chrysler has the options of certifying its engines on the light-duty truck procedure or of contracting out the testing but has apparently decided against these choices (see Chapter 8). Based on Chrysler's business decisions, the only possible courses of action EPA could take which would allow them to continue production of heavy-duty gasoline engines would be either a special provision for Chrysler alone or a relaxation of the requirements for all of the industry by eliminating the transient test. Neither option is fair to the rest of the industry because all have made substantial financial commitments. Chrysler cannot be classified as a small manufacturer, therefore, a special provision for Chrysler would result in a fundamental business disadvantage for other manufacturers. Elimination of the transient test for whatever reason would result in nearly 50 million dollars industry-wide in sunk costs which could not be recovered, and would yield no environmental benefits.

IV. <u>Conclusions</u>

1. Manufacturers of heavy-duty gasoline and diesel engines have collectively committed $47.5M or 67 percent of a total $70.6M required for the development of transient testing facilities. Most of these sunk costs cannot be recovered if the implementation of the transient test is cancelled or delayed. The outstanding transient test issues are, therefore, primarily technical or related to timing of implementation rather than economic.

2. A delay in the implementation of the transient test would allow the deferral of a collective $21.1M in investment capital for approximately the same period of time as the delay.

3. Most gasoline and diesel manufacturers have indicated that a steady-state test with equivalently stringent

standards as the transient test, and/or carryover of emissions data from 1983 certification, will be required as an option to the transient test for 1984. Most diesel manufacturers recommend the steady-state test be retained as an option until the new NOx and particulate standards become effective.

4. Chrysler has indicated it may leave the gasoline engine market at the time the transient test becomes mandatory. There is no fair way to provide regulatory relief for Chrysler alone.

References

1. Derived from Comments Submitted to EPA Public Docket No. A-81-20.

2. Derived from Comments Submitted to EPA Public Docket No. A-81-11.

3. "Summary and Analysis of Comments to the NPRM, 1983 and Later Model Year Heavy-Duty Engines Proposed Gaseous Emission Regulations," December 1979.

4. "Regulatory Analysis and Environmental Impact of Final Emission Regulations for 1984 and Later Model Year Heavy-Duty Engines," U.S. EPA, OMSAPC, December 1979.

CHAPTER 4

A REVIEW OF EPA'S TRANSIENT TEST CYCLES

I. Introduction

Since their original proposal in February of 1979, EPA's transient test cycles have been the subject of a vigorous technical controversy. The heavy-duty gasoline and diesel engine manufacturers have continously criticized the cycles, characterizing them as unrepresentative of real truck operation, the victims of flawed data and incorrect development methodologies. These arguments were reiterated in response to the June 17, 1981, Federal Register questions, and in comments received in response to the "Revised 1984 Heavy-Duty Engine Emission Regulations."

A great deal has already been written on this subject. The original Summary and Analysis of Comments of the 1984 FRM[1] argued strongly against most of the industry's technical criticism. Later, continued industry criticism arose in A.D. Little Inc.'s report to the MVMA[2] and Caterpillar Tractor Co.'s Real Time Cycle Report.[3] This study will briefly review recent criticisms and review the available emission data to determine if measurable irregularities are indeed present in the EPA test cycles.

II. Summary of Comments

A. Flawed Data Base

The raw data used in generating EPA's test cycles were accumulated in the early 1970's in the CAPE-21 Project. Over 100 trucks and buses were instrumented, and a variety of operational parameters (speed, RPM, load factors, etc) were recorded.

The EMA characterized the CAPE-21 project as "plagued by equipment malfunctions and overwhelmed with false data."[5] EPA in fact classified approximately one-third of the total data base as erroneous, and removed it. EMA, however, argued that all data taken on the same instrumentation on the same day should have been discarded, not merely that which was clearly incorrect. Using this and other criteria,* Caterpillar[3] discarded nearly three-fourths of the CAPE-21 data. Following this logic, a large percentage of the data upon which the EPA cycle is based was incorrect. EPA's cycle is thereby questionable, if not completely unrepresentative, in the judgment of the EMA.

* See Chapter 5 of this study, "The Real Time Cycle: An Alternative Heavy-Duty Diesel Engine Driving Cycle."

Another criticism of the CAPE-21 data base, expressed most recently by A.D. Little,[2] was that the data base sample size (i.e. number of trucks) was too small. Too small a sample size limits the accuracy with which the "average" truck can be characterized, and, hence, the representativeness of the test cycles.

B. Inappropriate Generation Methodology

EPA used the Monte Carlo statistical technique to construct candidate cycles from the second-by-second CAPE-21 data. In practice, one second of operational data (engine speed, engine power) was randomly selected by a computer; the next second was probabilistically selected, based upon the observed frequency of occurrence of that transition in the CAPE-21 data base. This probabilistic sampling continued until a candidate cycle was created. These candidate cyles (of which there were thousands) were then compared to and screened against statistical summaries of CAPE-21 parameters. The cycles closest to the CAPE-21 data base were then selected to make up the final test cycle.

The most exhaustive criticism of this methodology was made by A.D. Little[2], although over time almost every manufacturer criticized EPA on this matter. Among A.D. Little's conclusions were the following:

1. The methodology failed to consider all important operational parameters (e.g., engine temperature, time sequencing, and history of operation).

2. The Monte Carlo methodology cannot adequately represent actual operation, since it neglected sequential engine operation and produced erratic second-by-second test cycles - not the characteristic speed/load shift patterns seen in actual trucks.

3. The cycle segments were too short, requiring unrepresentative manipulations to give the Monte Carlo technique the appearance of sampling the entire data base.

4. The statistical filter used to screen the candidate cycles was incomplete and inconsistently applied, permitting unrepresentative parameters to enter the test cycle.

In short, A.D. Little concluded that the EPA cycles were unrepresentative of both the data base and real world trucks. The industry has used A.D. Little's analysis to substantiate its earlier criticisms, and to argue for adoption of its own engine test cycles. (See Chapters 5 and 6).

C. Operational Problems

The industry has also argued that the EPA cycles' erratic construction will lead to repeatability and correlation problems when used in actual emission testing. The gasoline engine manufacturers cite a study by EPA staff[6] which showed that gasoline engine emissions, as measured over EPA's test cycle, are sensitive to the dynamometer control system calibration (and perhaps the control system itself). In addition, the study indicated that other test validation criteria may need to be tightened to minimize the chances of repeatability and correlation problems. The industry has used this study to argue that a test cycle which is too transient (high frequency of changing speed and torque commands) may yield unrepresentatively high emissions results, and when combined with the variety of potential control systems and control system calibrations, may yield unrepeatable emissions from lab-to-lab. Some manufacturers have also argued that the EPA cycle is too transient to provide repeatable results from test to test, especially on cold starts.

The diesel engine industry also raised similar concerns about the repeatability and lab-to-lab correlation potential of the EPA cycle. Based upon these concerns, the EPA/EMA Round Robin correlation program was initiated, in which several diesel engines were circulated among the manufacturers and EPA. The gasoline manufacturers, through MVMA, have also requested that a similar (though smaller scale) project be initiated with EPA for their engines.

II. Analysis of Comments

A. Test Cyle Representativeness (Overview)

To begin this discussion, it is best to review how the representativeness of an emissions test cycle can be evaluated.

To date, both EPA and the industry have argued questions of representativeness on the basis of statistical comparisons: if the test cycle is operationally and statistically representative of the "average" on-road truck, then the emissions measured over that test cycle will be representative of on-road emissions. This is a logical, but hypothetical argument; its utility in discriminating between test cycles is valid only up to a point. Its fundamental weakness is that statistical differences represent unquantified, perhaps undetectable, emission differences. Secondly, the correlation between test cycles and the real world, i.e., the predictive utility of the test cycles in insu[illegible] real world emission reductions, may not be as sensitive to minor statistical and operational variations as some have claimed. Comparative emission data represent the only means for resolving how statistically and operationally representative a test cycle has to be.

The preferred method is to review laboratory emission data. In as fine a breakdown as possible, compare the emission effects of changes to test cycle parameters. These results can be used to extrapolate the emissions effect of statistical and operational differences between cycles, or a particular type of operation in a given cycle. This has already been done in several cases by EPA,[4,6] and will likely be continued during analysis of the data generated from the EPA/EMA Round-Robin Test Program[7,8] and the suggested EPA/MVMA correlation project. EMA's and MVMA's alternate test cycles provide a further basis for comparison, i.e., between different cycles developed in different ways as a means of evaluating the cycle generation methodologies. From this analysis, one can judge if any given test cycle yields grossly different and, hence, unrepresentative emissions.

B. The Validity of Specific Criticisms

The diesel engine industry concentrated it's criticism on the CAPE-21 data base. EPA had argued earlier[1] that the data collection and editing were performed with sufficient care to preclude the use of void data for test cycle development. In generating their own Real Time Cycle, engineers at Caterpillar were stricter in their criteria for editing data (see Chapter 5). Rather than debate the merits of either approach, however, we need only review the similarity of outcomes. As discussed in detail in Chapter 5, the EPA and EMA (Real Time) cycles are statistically similar, both being close to their respective CAPE-21 data bases (which themselves are quite similar). Both cycles yield NOx emissions which are comparable; particulate and HC emissions are somewhat less on the EMA cycle, but to a much lesser degree than differences observed between subcycles (NYNF vs. LAF), i.e., between cycles of significantly different operational characteristics. Furthermore, emissions measured over both cycles correlate extremely well with each other. In other words, if applied technology affects a change in emissions on one cycle, a proportional change will be measurable on the other cycle (and presumably in-use if both cycles are representative). If applicable emission baselines and standards are adjusted to reflect the differences in absolute emission levels between cycles, there remain no practical differences between the test cycles. The editing of the CAPE-21 data base becomes irrelevant, as do other claims of EPA cycle unrepresentativeness, from a practical testing standpoint.

EPA's analysis of the A.D. Little report[4] addressed the issue of truck sample size. EPA concluded that A.D. Little held EPA to unreasonable and impractical standards of accuracy. For example, A.D. Little concluded that over 1000 trucks were necessary to adequately characterize certain truck parameters. At more reasonable accuracy criteria, the truck sample size was large enough to confidently establish 41 of 42 parameters. Furthermore, CAPE-21 was the largest on-road truck study attempted up to that time. Such criticism neglects real world practicalities and the diminishing returns of accuracy with continued testing.* Despite the fact that they rejected

75 percent of the CAPE-21 data (as opposed to EPA's 33 percent), Caterpillar's technical personnel concluded that a sufficiently large data base remained to generate a representative test cycle - the Real Time Cycle.[3]

The gasoline engine industry's criticism focused mainly on the manipulation of the CAPE-21 data base, and the generation of EPA's cycles. Much has also been written about the cycle generation methodology, in particular, the Monte Carlo technique. A.D. Little's report to the MVMA (2) is the best example of the industry's position. To address this criticism, we repeat the conclusions of EPA's analysis of the A.D. Little report (4):

1. "A.D. Little's criticisms of EPA's cycle development methodology are based upon statistics and conjecture. No emission data is presented or referenced to substantiate any claims of engine or chassis cycle unrepresentativeness."

2. "A.D. Little's statements concerning combustion engine emissions are based upon a brief literature review, and not upon actual "hands-on" experience with emission testing or emissions control. A.D. Little therefore attributes many engine parameters...with larger than life emission significance, whereas only a few...will in actuality dominate the results of laboratory emissions test."

3. "The majority of A.D. Little's analysis of test cycle validation is incorrect, being based upon incorrectly-applied statistical tests and incorrectly-chosen comparative parameters."

4. "A.D. Little's harsh criticism of the weakness in EPA's methodology neglects to mention that the weakness was not imposed by EPA error, but rather by fundamental limitations which the input data placed upon the applicable statistical techniques, and by the compromises required to compress the vast data base into a workable test procedure." (Note that in their cover letter to the MVMA, A.D. Little stated that they knew of no entirely correct statistical way that test cycles could be derived from the CAPE-21 data.)

5. "A.D. Little's arguments were not only narrow in focus (neglecting practicalities and ignoring emissions), they were entirely negative. No single alternative to EPA's methodology was advanced. No

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* The complete in-depth analysis of sample-size, and EPA's comprehensive review of the A.D. Little Report can be found in [4].

evidence was presented that EPA neglected a more representative approach in lieu of the methodology chosen. No specific suggestions were made about how the cycles could be improved."

6. "ECTD sees nothing in the A.D. Little Report to warrant changing the conclusion that the engine cycles are sufficiently representative of the data base. The implications from all emission data collected to date on the engine cycles are that emissions are not exaggerated by the Monte Carlo technique. Changes to the engine cycles to improve the agreement of their operational parameter summary percentages with those of the CAPE-21 data cause negligible or minor (less than 5 percent) changes in measured emissions. This is true even for the most operationally-sensitive modes and emissions evaluated...As substantiated by EPA's engine cycle emission data, A.D. Little overestimates the emissions sensitivity of the test cycles to the cycle generation methodology...It was a highly conjectural overestimation, being based upon absolutely no emission data whatsoever."

Emission data is available to support these conclusions. To evaluate the effect of the cycle generation methodology, EPA reviewed data on transient throttle response,[6] and transient test emissions vs. steady-state emissions for uncontrolled gasoline engines.[4] The data[6] indicated that below the range of dynamic throttle activity normally used to control a gasoline engine during a transient cycle, emissions were unaffected, i.e., decreasing transient operation did not affect emissions. This implies that the EPA cycle is not excessively transient, since a dampened throttle controller mechanically smoothed the cycle and emissions remained unaffected. Furthermore, average emission levels of fifteen 1969 gasoline engines on both the EPA transient test and the old 9-mode steady-state procedures were compared. If unrepresentative transient operation were present, one would expect uncontrolled transient emissions to significantly exceed those measured on the steady-state tests. In fact, the emission levels of both tests were not dramatically different;* EPA transient HC emissions were actually 9 percent less.

In the same report,[4] EPA evaluated statistical differences between cycles. Small differences in operational percentages (which A.D. Little argued rendered the EPA cycle unrepresentative) produced minimal emission changes (less than 5 percent) for the most operationally-sensitive modes in the

* Note that this comparability between steady-state and transient test procedures has only held for uncontrolled engines, i.e., engines to which no technology has been applied for emission control.

test cycle. In short, emissions measured over the entire test cycle are not sensitive to small changes in summary statistics. Finally, the close, correlatable relationship between the emissions measured on EPA cycles and the MVMA cycle (a smoothed, minimally-restructured version of the EPA cycle), and the EMA cycle (a cycle developed using an entirely different methodology), leads one to the conclusion that the EPA cycles are technically sound. We are unaware of any contradictory emission data.

C. Operational Problems

Correlation and repeatability are important facets of emission testing. This is especially so when a manufacturer's certificate of conformity depends upon the outcome of confirmatory testing. For light-duty vehicles, correlation and repeatability concerns led to the standardization of test equipment (e.g. chassis dynamometers). Calibration and testing protocols have also been standardized over time. All represent the accumulated work and experience of technical personnel throughout the industry and EPA.

The old heavy-duty test procedures are no different, nor is the new transient test. Resolution of repeatability and correlation problems is an inevitable task when a new test procedure is adopted. This is especially true when new equipment for engine control and emission sampling and measurement are required. EPA anticipates that a number of technical amendments to the transient test will need to be made; many have indeed already been made.[1] Aside from the repeatability and correlation aspects, changes recommended by industry will also be made to reduce complexity and cost. (All of these forthcoming technical changes will not be discussed here; they will be addressed in the Summary and Analysis of Comments to the "Revised 1984 Heavy-Duty Engine Emission Regulations.")

The industry has speculated that EPA's transient test will be more conducive to repeatability and correlation difficulties. A report by EPA staff[6] indicated that there is potential for gasoline engine emission variability within the range of the transient test validation criteria. This by no means guarantees that repeatability is a problem. Other test procedures also have validation criteria, usually specified as ranges of operation which the engine vehicle may not exceed during the test.* Good engineering practice, however, requires testing not at the full range of possible calibrations, but at that closest to nominal to minimize repeatability problems.

* The 9-mode steady-state test is run at 2000 ±100 RPM, the 13-mode at the specified speed ±50 RPM; torque values for both tests are run at ±2 percent of the maximum engine torque. The light-duty test procedure requires a driver to remain within a specified mph band about the driving cycle.

The same is true when running a transient test cycle - any transient test cycle - on an engine dynamometer. However, a technical problem arises when using an electro-mechanical control system to maneuver a high inertia engine/dynamometer combination through a continuously varying cycle. The control system design may in fact determine what the optimal validation statistics are.* This is a hardware/control system problem - not a cycle problem, i.e., the system will respond similarly for any reasonably similar cycles. (For example, there are no substantive differences between cycle validation statistics for engines tested by EPA on both the EPA and MVMA cycles.) There is no evidence that EPA's cycle is any more susceptible to control system calibration than any other transient cycle.

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* For example, EPA uses a proportional-feedback control system.[9,10] The difference in electrical signal between the command voltage and the feedback voltage "drives" the throttle controller to correct the discrepancy, i.e., until the differential voltage is zero. In this way the engine is made to follow the cycle as the feedback signal continually "chases" the command signal. However, the inertia of the electro-mechanical system (including the engine) is high; if too strong an initial "push" (too high an electrical gain) is given to effect a torque change, the control system will overshoot the desired torque. An even higher gain will cause oscillatory motion (an "underdamped" response) about the desired torque, pumping the accelerator pump in an unrepresentative manner and drastically increasing emissions[6]. This dynamic characteristic is entirely a function of the analog control system's design. Another type of analog control system (e.g., proportional plus derivative feedback - PDF) or a real-time microprocessor system will yield entirely different transient characteristics.

Transient cycle validation criteria are least squares regression statistics; mathematically perfect regression statistics are 1.000 (regression line slope) and 1.000 (correlation coefficient). EPA's prototype control system, in order to respond quickly enough to approach the mathematically perfect regression statistics, must be given so much gain that oscillatory, dynamic instability occurs. EPA's control system is quite capable of following a transient cycle very closely without resonant instability . This does not occur, however, at the mathematically perfect regression values, but at values somewhat less. A different type control system will no doubt perform differently, and have its own optimum validation statistics based upon its own characteristic equations of motion.

The report by EPA staff[6] recommends further testing. In this way, the speculation of the past gives way to reasoned engineering analyses of technical issues such as these. A logical result of this testing may be standardized control system design, and perhaps revised validation criteria. Assessments of emission sampling equipment would also be a natural extension of further testing, especially for the continuous sampling systems required to test diesel engines.

Such testing is already taking place in the EPA/EMA Round Robin Correlation Program. Preliminary results[7,8] indicate reasonable correlation between laboratories, and repeatable measurements within labs. Widespread fears of dramatic correlation problems have not been realized. Steady-state 13-mode particulate results were most variable (with a coefficient of variation of ±16.7 percent relative to ±8.7 percent for the EPA transient test); this is primarily due to the lack of a standardized steady-state particulate test, which itself indicates how important standardization is in achieving repeatability between labs. Transient HC data were more variable than 13-mode HC (±12.6 percent vs. ±8.3 percent), but not to an extent indicative of fatal problems, and likely attributable to differences in emission sampling equipment (to which continuously sampled diluted exhaust HC is sensitive). The initial results of this test project are encouraging, and give no indication to any reasonable reviewer that fundamental, unresolvable problems exist. (A more comprehensive review of the results can be found in [7,8].)

Repeatability of emissions with baseline gasoline engines on the transient procedure at EPA's laboratory have been reported earlier.[9,10] Average coefficients of variation for all engines tested were ±5.9 percent (HC), ±5.8 percent (CO), and ±6.3 percent (NOx). These are reasonable but not exceptional, and the degree of repeatability was engine dependent. Again, no fundamental problems were observed. An in-depth correlation effort between EPA and the gasoline engine manufacturers has yet to begin, although MVMA has requested such an effort. Since gasoline engines may indeed be most sensitive to control system parameters, it is important for the identification of test procedure refinements for EPA to follow through with such a program. (Emission sampling for heavy-duty gasoline engines is relatively straightforward, being a direct extension of light-duty sampling technology; only minor problems, if any, are anticipated in this facet of correlation.)

Finally, with mandatory certification on the transient test procedure likely beginning for 1985, over two years remain for procedure refinement. We are aware of no fundamental problems with the test (either cycle related or operationally related) which would preclude or potentially invalidate ongoing development testing. (The gasoline engine manufacturers are well along in characterizing their product lines on the transient test, and have begun initial development work; the diesel engine industry is routinely running transient tests, and their engines need far less development work to meet applicable standards.) We also note that the industry's transient facilities are all new and incorporate the latest technology, whereas EPA still uses its prototype facility. *Should test equipment standardization be necessary to assure* correlation, upgrading EPA's test sites to match the manufacturers' would impact the industry least, would ease industry concerns about correlation problems at the time of confirmatory testing, and would give EPA a better, more productive test site. At any rate, we see no time constraint preventing procedural refinements, should they be found necessary.

IV. Conclusions

1. No test data have yet been advanced to find EPA's transient cycles to be unrepresentative. All emission data to date continue to confirm their acceptability. In fact, the EPA cycles correlate well with the EMA and MVMA alternative cycles, from which the industry removed all operation with which it objected.

2. No fundamental problems of repeatability and inter-lab correlation have been observed for the EPA test. We anticipate a succession of technical amendments to the procedure as experience is gained throughout the industry, and in response to joint correlation projects. All work necessary to refine the test procedure should proceed as required. A joint correlation program between EPA and the gasoline engine manufacturers should be initiated as soon as practical.

References

1. "Summary and Analysis of Comments to the NPRM: 1983 and Later Model Year Heavy-Duty Engines - Proposed Emission Regulations," December 1979.

2. "A Review of the Heavy-Duty Gasoline Engine Certification Test Cycles," Final Report to the MVMA, Arthur D. Little, Inc., Cambridge, April 1981.

3. "Evaluation of the Federal Test Procedure for Heavy-Duty Diesel Engines for 1984 and the Development of the Real Time Test Cycle," W.L. Brown, Caterpillar Tractor Co., Research Report 88-29, File 18967, June 22, 1981.

4. "Analysis of Arthur D. Little Inc.'s Report to the MVMA: A Review of the Heavy-Duty Gasoline Engine Certification Test Cycles,'" ECTD Staff Report, January 1982.

5. Derived from comments submitted to EPA Public Docket No. A-81-11.

6. "Heavy-Duty Gasoline Engine Emission Sensitivity to Variations in the 1984 Federal Test Cycle," T. Cox, SAE Paper No. 801370, October 1980.

7. "Status of EPA/EMA Cooperative Test Program," A. Azary, EPA Status Report, March 1982.

8. "Preliminary Report on Statistical Analysis of Heavy-Duty Diesel Engine Emissions Data," N.J. Barsic, prepared for the Engine Manufacturers Association/Technology and Methods Subcommittee.

9. "1969 Heavy-Duty Engine Baseline Program and 1983 Emission Standards Development," T. Cox, et al., EPA Technical Report No. SDSB-79-23, May 1979.

10. "1972-73 Heavy-Duty Engine Baseline Program and NOx Emission Standard Development," T. Cox, et al., EPA Technical Report No. AA-SDSB-81-01, March 1981.

CHAPTER 5

THE REAL TIME CYCLE: AN ALTERNATIVE HEAVY-DUTY DIESEL ENGINE DRIVING CYCLE

An alternative heavy-duty diesel driving cycle, the Real Time Cycle (RTC), has been developed by the Caterpillar Tractor Company. It was developed in response to industry-wide concern over the methodology used to generate the EPA driving cycle and the resulting representativeness of EPA's cycle. The Engine Manufacturers Association has proposed the RTC be allowed as an option to the EPA driving cycle for the certification of heavy-duty diesel engines. The specific recommendations of the manufacturers, and factors under consideration by EPA concerning the RTC as a test option, will be discussed in this chapter.

A. Summary of Comments[1,2]

Most manufacturers and the EMA have made specific recommendations concerning the use of the Real Time Cycle for certification testing. These comments are summarized below.

Engine Manufacturers Association - EMA recommends EPA allow manufacturers to certify engines on either the Federal Test Procedure or on a modified cycle such as the RTC.

Caterpillar - Caterpillar recommends EPA provide the option of using either the RTC or the EPA cycle for certification of heavy-duty diesel engines.

Cummins - Cummins has no reason to support or object to the RTC as an option as long as EPA and industry work toward the eventual use on only one test cycle.

Daimler-Benz - DB's April 12 submission of comments indicated that it had not had time to comment, but will do so later.

General Motors - GM recommends EPA initiate a cooperative test program with industry to improve the Federal Test Procedure (EPA driving cycle), However GM is not opposed to the use of the RTC as an option.

International Harvester - IH believes the RTC should be used instead of the EPA cycle, however IH does not oppose the RTC as an option.

Mack - Mack would consider the use of the RTC only after a thorough study of the cycle, including round robin testing at manufacturers' and EPA laboratories.

B. Analysis of Comments

In this analysis, we address the technological basis, representativeness, and relative stringency of the Real Time Cycle.

1. Cycle Development[3]

Caterpillar developed the RTC because of concern over the accuracy of simulation of in-use truck operation represented by the EPA cycles. This concern stemmed from alleged instrumentation problems in the CAPE-21 project which resulted in a significant amount of questionable data being accepted into the data base, and from the methodology EPA used to generate the cycle.* Caterpillar's objectives in developing the RTC were to generate a cycle from the portion of the CAPE-21 data base which it considered valid, and to construct the cycle so it better represented its judgment of real-world truck operation.

Caterpillar constructed the cycle in the following manner: First, the entire data base was edited to remove the questionable data using the following criteria for acceptance or rejection:

a. Entire truck-days of operation were either accepted or rejected. The reasoning is that repairs were probably not made on instrumentation during the same days in which malfunctions occurred.

b. Truck-days which exhibited more than 10 percent spurious data for both engine rpm and power were rejected.

c. A positive correlation between engine torque and change in rpm for at least 50 percent of the time of operation was required for acceptance.

d. Discrepancies between time at idle rpm and idle power could not occur more than 15 percent of the total operating time for acceptance.

e. Truck days which had over 10 percent of the events at less than negative 30 percent power were rejected.

This editing left 23 truck-days of data, or about 25 percent of the original data base.

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* See Chapter 4 of this study.

Statistical parameters were then chosen to characterize the edited data base. These were mean values and cumulative distributions of %rpm, %power, and positive %rpm. The % idle time and distribution in length of idle were also used. These statistical parameters, which characterized the edited data base, then became the target values for the construction of the new test cycle.

To construct the new test cycle, the data were broken down into the smallest elements which did not interrupt the normal driving sequence. These elements were defined as the vehicle operational events which occurred between vehicle stops. The elements were then assembled into trial test segments which matched, as closely as possible, the desired statistics of the categories they represented. The categories were: New York Freeway (NYF), New York Non-Freeway (NYNF), Los Angeles Freeway (LAF), and Los Angeles Non-Freeway (LANF). The idle time and category weighting were adjusted to match the original CAPE-21 data base, since it was unlikely that instrument error would change these parameters. The trial test segments were then tested against the data base for maximum deviation of cumulative distributions and then were compared visually. The best cycles were selected and assembled into an entire driving cycle.

The result was a heavy-truck engine driving cycle, the "Real Time Cycle," which matched very closely the statistics of the edited CAPE-21 data base, and which the diesel engine manufacturers determined was more representative of in-use truck operation than the EPA cycle.

2. Statistical Analysis

A comparison of the target statistics from the edited data base, the RTC statistics, and the EPA cycle statistics is shown in Table 5-1. Additional statistics from the RTC, EPA cycle, and the original CAPE-21 data base are listed in Table 5-2. The most important statistical differences between the RTC and the EPA cycle are:

a. The RTC includes a NY Freeway segment; the EPA cycle does not include the NY Freeway segment.* (The NY Freeway segment is higher in mean %rpm and higher in mean %power than the NY non-Freeway segment.)

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* EPA omitted the NY Freeway segment because invalid data had been included in the data base and the weighting for this segment was small compared to the other segments.[4]

Table 5-1

Target, RTC, and EPA Cycle Statistics [3]

	Los Angeles Non-Freeway			Los Angeles Freeway		
	Target	Real Time	EPA	Target	Real Time	EPA
Average % RPM	40.7	41.8	43	80.0	83.5	83
Average % Power	24.1	25.9	26	58.9	56.4	56
Average Positive Acceleration	4.6	5.7	6.1	1.9	1.2	2.4
% Idle Time	35.0	32.7	34	2.0	1.4	2.3
Category Weighting	23.7	27.3	25.0	26.3	25.1	25.0

	New York Non-Freeway			New York Freeway		
	Target	Real Time	EPA	Target	Real Time	EPA
Average % RPM	41.5	47.1	-	17.7	19.8	20
Average % Power	41.0	54.4	-	19.4	22.3	16
Average Positive Acceleration	2.8	4.6	-	3.8	3.6	5.6
% Idle Time	19	21	-	51.0	51.0	55
Category Weighting	9.0	5.9	0	41.0	41.7	50.0

	Overall		
	Target	Real Time	EPA
Average % RPM	41.7	43.4	41.5
Average % Power	32.8	33.7	28.5
Average Positive Acceleration	3.9	4.2	4.6
% Idle Time	31.4	31.8	36.6

Table 5-2

RTC, EPA Cycle, CAPE-21 Data Base Statistics

Parameter	RTC	EPA	CAPE-21
Torque			
Mean (%)	30.57	28.32	27.00
Percent of Cycle Time			
Accel. (%)	18.21	15.68	15.10
Decel. (%)	18.37	16.85	15.25
Cruise (%)	22.48	20.43	18.75
Motor (%)	7.98	11.43	15.00
Idle (%)	32.96	35.61	35.00
RPM			
Mean (%)	42.78	41.52	41.75
Percent of Cycle Time			
Acceleration (%)	23.45	21.77	21.50
Deceleration (%)	22.48	21.93	19.50
Cruise (%)	19.74	16.10	19.50
Idle (%)	34.33	40.20	39.00

b. The RTC is 5.2 percent higher in mean %power, overall than the EPA cycle.

c. The RTC is 4.8 percent lower in %idle time, overall than the EPA cycle.

d. The sequential ordering of the cycle segments on the RTC is LANF, LAF, NYF, and NYNF. The ordering on the EPA cycle is NYNF, LANF, LAF, NYNF.

The statistical differences cited here may or may not affect engine emission levels. A potentially significant factor is that the observed engine work done over the test cycle (BHP-hr) is higher by 16-18 percent on the RTC. Furthermore, the reordering of the segments in the RTC permits the engine to operate in the high power LAF mode earlier in the cycle, which may lead to an earlier engine warm-up (although operation in the LAF segment of the RTC is initially cooler than on the EPA cycle). Inclusion of the NYF segment is one obvious reason why the RTC BHP-hr is higher, possibly affecting emissions.

3. Emissions Analysis

Heavy-duty diesel engine manufacturers and EPA have tested several engines on both the Real Time Cycle and the EPA cycle for the purpose of comparing emissions results. All of the available data has been collected and is summarized in Table 5-3. Results are also plotted in Figures 5-1, 5-2, and 5-3. Since typical diesel CO emissions are much lower than statutory levels, this pollutant comparison was not included.

Data from 30 engines/configurations showed excellent statistical correlation between the two test cycles for all three pollutants; r^2 values were .94, .98, and .90 for HC, NOx and particulates, respectively. However, definite emissions differences between the two test cycles were observed. There was an average RTC HC emissions offset* of -16.0 percent from the EPA cycle with a range of -35.4 percent to +9.4 percent and a coefficient of variation of .62. The average NOx emissions offset was +1.0 percent from the EPA cycle with a range of -12.6 percent to +17.1 percent and a coefficient of variation of .72. The average particulate emissions offset on the RTC was -9.4 percent from the EPA cycle with a range of -25.7 percent to +18.9 percent and a coefficient of variation of 1.17.

* $\% \text{ Offset} = \frac{\text{RTC} - \text{EPA}}{\text{EPA}} \times 100\%$

Table 5-3

Summary of Emissions Data EPA Cycle vs. Real Time Cycle

Engine	Tested By	Cycle	Number and Type of Tests	HC (g/BHP-hr)	NOx (g/BHP-hr)	Particulate (g/BHP-hr)
Mack 676	EPA	RTC	4HS	.55	8.56	.777
Mack 676	EPA	EPA	4HS	.65	8.40	.752
% Difference*				-15.4%	1.9%	3.3%
Cummins VTB903	EPA	RTC	4HS	1.27	5.01	.504
Cummins VTB903	EPA	EPA	4HS	1.60	5.07	.544
% Difference				-22.6%	-1.2%	-6.7%
IHC DT-210	IHC[a]	RTC	1-3CS, 2-7HS	.78	6.80	-
IHC DT-210	IHC	EPA	1-3CS, 2-7HS	.89	7.20	-
% Difference				-12.4%	-5.6%	-
IHC DTI-210	IHC	RTC	1-3CS, 2-7HS	.85	4.16	-
IHC DTI-210	IHC	EPA	1-3CS, 2-7HS	1.07	4.15	-
% Difference				-20.6%	-0.2%	-
IHC DTI-180	IHC	RTC	1-3CS, 2-7HS	1.06	4.73	-
IHC DTI-180	IHC	EPA	1-3CS, 2-7HS	1.19	4.94	-
% Difference				-10.9%	-4.3%	-
IHC 9.0L	IHC	RTC	1-3CS, 2-7HS	1.90	7.52	-
IHC 9.0L	IHC	EPA	1-3CS, 2-7HS	2.03	7.18	-
% Difference				-6.4%	-4.7%	

* $\% \text{ Difference} = \frac{\text{RTC} - \text{EPA}}{\text{EPA}}$

[a] Particulate data not included.

Table 5-3 (cont'd)

Summary of Emissions Data EPA Cycle vs. Real Time Cycle

Engine	Tested By	Cycle	Number and Type of Tests	HC (g/BHP-hr)	NOx (g/BHP-hr)	Particulate (g/BHP-hr)
Cummins #1[b]	Cummins	RTC	2HS	.48	7.46	.43
Cummins #1	Cummins	EPA	2HS	.55	7.50	.46
% Difference				-12.7%	-.53%	-6.5%
Cummins #2	Cummins	RTC	2HS	.91	7.92	.66
Cummins #2	Cummins	EPA	2HS	1.19	8.10	.66
% Difference				-23.5%	-2.2%	0.0%
Cummins #3	Cummins	RTC	2HS	.63	7.29	.56
Cummins #3	Cummins	EPA	2HS	.87	7.37	.70
% Difference				-27.6%	-1.1%	-20.0%
Cummins #4	Cummins	RTC	2HS	.67	5.42	.94
Cummins #4	Cummins	EPA	2HS	.94	4.63	.94
% Difference				-28.7%	17.1%	0.0%
Cat. 3208	IHC	RTC	4CS, 6HS	.84	8.57	.600
Cat. 3208	ICH	EPA	5CS, 12HS	1.30	7.68	.704
% Difference				-35.4%	11.6%	-14.8%
Mack #1[c]	Mack	RTC	-	.41	5.9	.46
Mack #1	Mack	EPA		.46	5.6	.51
% Difference				-10.9%	5.4%	-9.8%

[b] Engine models not specified.
[c] Emissions data derived from plots. Engine models and number and type of tests not specified.

Table 5-3 (cont'd)

Summary of Emissions Data EPA Cycle vs. Real Time Cycle

Engine	Tested By	Cycle	Number and Type of Tests	HC (g/BHP-hr)	NOx (g/BHP-hr)	Particulate (g/BHP-hr)
Mack #2	Mack	RTC	-	.46	8.4	.69
Mack #2	Mack	EPA		.55	7.8	.79
% Difference				-16.4%	7.7%	-12.7%
Mack #3	Mack	RTC	-	.87	9.0	.69
Mack #3	Mack	EPA		1.10	10.3	.85
% Difference				-20.9%	-12.6%	-18.8%
CAT 3208	IHC	RTC	4CS, 6HS	.85	8.59	.60
CAT 3208	IHC	EPA	5CS, 11HS	1.31	7.59	.70
% Difference				-35.1%	13.2%	-14.3%
Mack ETSZ-676	Cat	RTC	1CS, 7HS	.65	7.62	.63
Mack ETSZ-676	Cat	EPA	2CS, 12HS	.73	6.82	.53
% Difference				-11.0%	11.7%	18.9%
IHC DTI-466B	Cat	RTC	1CS, 6HS	.90	4.30	.70
IHC DTI-466B	Cat	EPA	2CS, 15HS	1.00	4.44	.69
% Difference				-10.0%	-3.2%	1.5%
Cat 3208	Cat	RTC	1CS, 7HS	1.18	8.79	.88
Cat 3208	Cat	EPA	5CS, 11HS	1.08	8.40	.86
% Difference				9.3%	4.6%	2.3%
Cat 3406	Cat	RTC	1CS, 6HS	.40	5.00	.73
Cat 3406	Cat	EPA	3CS, 14HS	.49	4.82	.83
% Difference				-18.4%	3.7%	-13.1%

Table 5-3 (cont'd)

Summary of Emissions Data EPA Cycle vs. Real Time Cycle

Engine	Tested By	Cycle	Number and Type of Tests	HC (g/BHP-hr)	NOx (g/BHP-hr)	Particulate (g/BHP-hr)
Cat 3208	Cat	RTC	3CS, 8HS	.98	9.24	.712
Cat 3208	Cat	EPA	2CS, 6HS	1.07	9.11	.854
% Difference				-8.4%	1.4%	-16.6%
Cat 3208 Model 1	Cat	RTC	5CS, 5HS	.88	13.96	.820
Cat 3208 Model 1	Cat	EPA	2CS, 3HS	1.04	14.13	1.04
% Difference				-15.4%	-1.2%	-21.2%
Cat 3208 Model 2	Cat	RTC	3CS, 6HS	2.40	6.42	.974
Cat 3208 Model 2	Cat	EPA	2CS, 8HS	2.70	6.38	1.24
% Difference				-11.1%	.63%	-21.4%
Cat 3406	Cat	RTC	3CS, 4HS	.37	7.26	.653
Cat 3406	Cat	EPA	3CS, 4HS	.48	7.62	.782
% Difference				-24.2%	-4.7%	-16.5%
CAT 3406 Model 1	Cat	RTC	3CS, 8HS	.47	11.56	.601
CAT 3406 Model 1	Cat	EPA	2CS, 5HS	.60	11.82	.726
% Difference				-22.0%	-2.2%	-17.2%
Cat 3406 Model 2	Cat	RTC	4CS, 4HS	.50	3.78	1.33
Cat 3406 Model 2	Cat	EPA	5CS, 5HS	.57	4.03	1.79
% Difference				-11.8%	-6.2%	-25.7%
Cat 3406 Model 3	Cat	RTC	2CS, 6HS	.77	3.64	2.27
Cat 3406 Model 3	Cat	EPA	3CS, 4HS	.89	4.12	2.20
% Difference				-12.6%	-11.7%	3.2%

Table 5-3 (cont'd)

Summary of Emissions Data EPA Cycle vs. Real Time Cycle

Engine	Tested By	Cycle	Number and Type of Tests	HC (g/BHP-hr)	NOx (g/BHP-hr)	Particulate (g/BHP-hr)
Cummins VTB-903	DDA[a]	RTC	1CS, HS	1.73	4.80	-
Cummins VTB-903	DDA	EPA	1CS, HS	1.98	5.07	-
% Difference				-12.6%	5.3%	-
Det. Diesel 8V-92 Model 1	DDA[a]	RTC	2HS	.72	4.26	-
Det. Diesel 8V-92 Model 1	DDA	EPA	2HS	.81	4.60	-
% Difference				-10.9%	-7.4%	
Det. Diesel 8V-92 Model 2	DDA[a]	RTC	3HS	.73	7.69	-
Det. Diesel 8V-92 Model 2	DDA	EPA	3HS	.68	8.38	-
% Difference				-7.3%	-8.2%	
Det. Diesel 8.2L	DDA[a]	RTC	3HS	.92	5.44	-
Det. Diesel 8.2L	DDA	EPA	3HS	1.14	5.78	-
% Difference				-19.3%	-5.9%	

[a] Particulate data not included.

These emissions offsets are significant, especially considering the excellent statistical correlations between the two test cycles. The relatively high coefficients of variation indicate there is a wide range of emissions differences among the different diesel engines tested.

In diesel engines, HC emissions are in large part attributable to residual fuel in the injector sac. The sac volume is constant regardless of the amount of fuel injected; as the load is increased (increased fuel injection), the mass rate of HC emissions from the sac remains constant. However, the brake specific rate of HC emissions (g/BHP-hr.) decreases at higher loads, since, the denominator (power) is increasing while the numerator (mass HC) remains the same. This may explain in large part the difference in HC emissions, given that the test cycles both exercise the engine in fundamentally the same way. Mathematically, an increase of 17 percent in BHP-hr. would result in a 15 percent reduction in the measurement of brake-specific HC:

$$\frac{1}{1.17}\,\frac{\text{EPA}}{\text{RTC}} = .85$$

This is nearly the entire observed HC offset.

The observed emissions offsets between the RTC and the EPA cycle indicate that the RTC is not as stringent as the EPA cycle at the same numerical level of emission standards. The RTC does, however, correlate very well with the EPA cycle for many different engines indicating that emissions from one cycle can be accurately predicted from those from the other. The excellent correlation also indicates both cycles are comparable in the ability to predict in-use emissions, and that there is no inherent advantage in favoring one cycle over the other - as long as the respective emission standards reflect equivalent stringency. Given the difference in cycle generation methodologies and the correlatable emission results, and the reasonable presumption that the HC emissions offset is primarily attributable to the difference in load factor between the cycles, we conclude that both cycles are comparably representative.

The emission standards for the RTC can be adjusted to levels of equivalent stringency as the EPA cycle by substituting the EPA standards in the linear regressions from Figures 5-1 and 5-2. Using this method and EPA standards of 1.3 g/bhp-hr HC and 10.7 g/bhp-hr NOx, the respective standards for the RTC would be:

HC 1.10 g/bhp-hr NOx 10.6 g/bhp-hr

The advantage to using this approach is that it is direct and accurately reflects the emission difference at the level of the

FIGURE 5-1

EPA Cycle vs. RTC BSHC Emissions

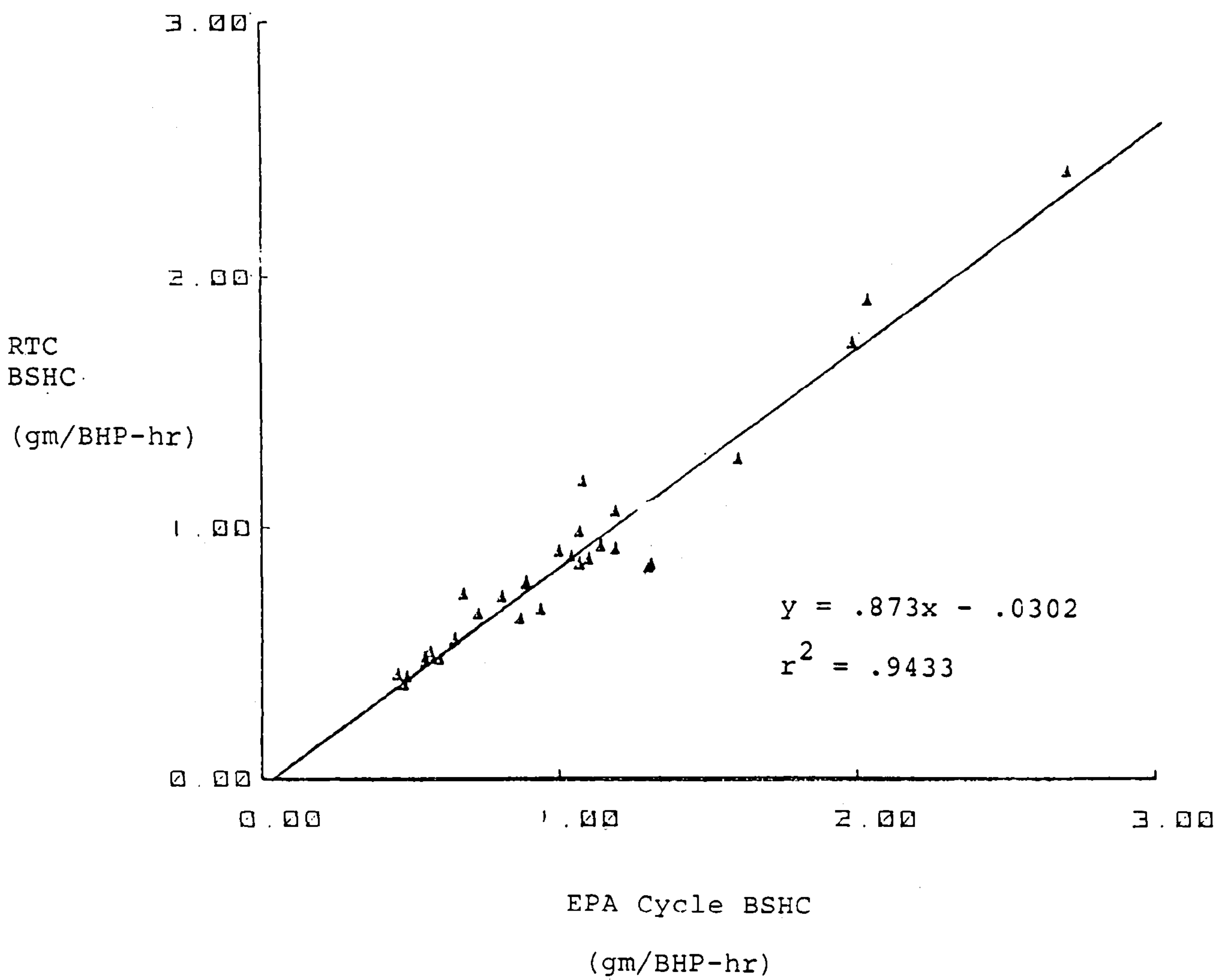


FIGURE 5-2

RTC vs. EPA Cycle BSNOx Emissions

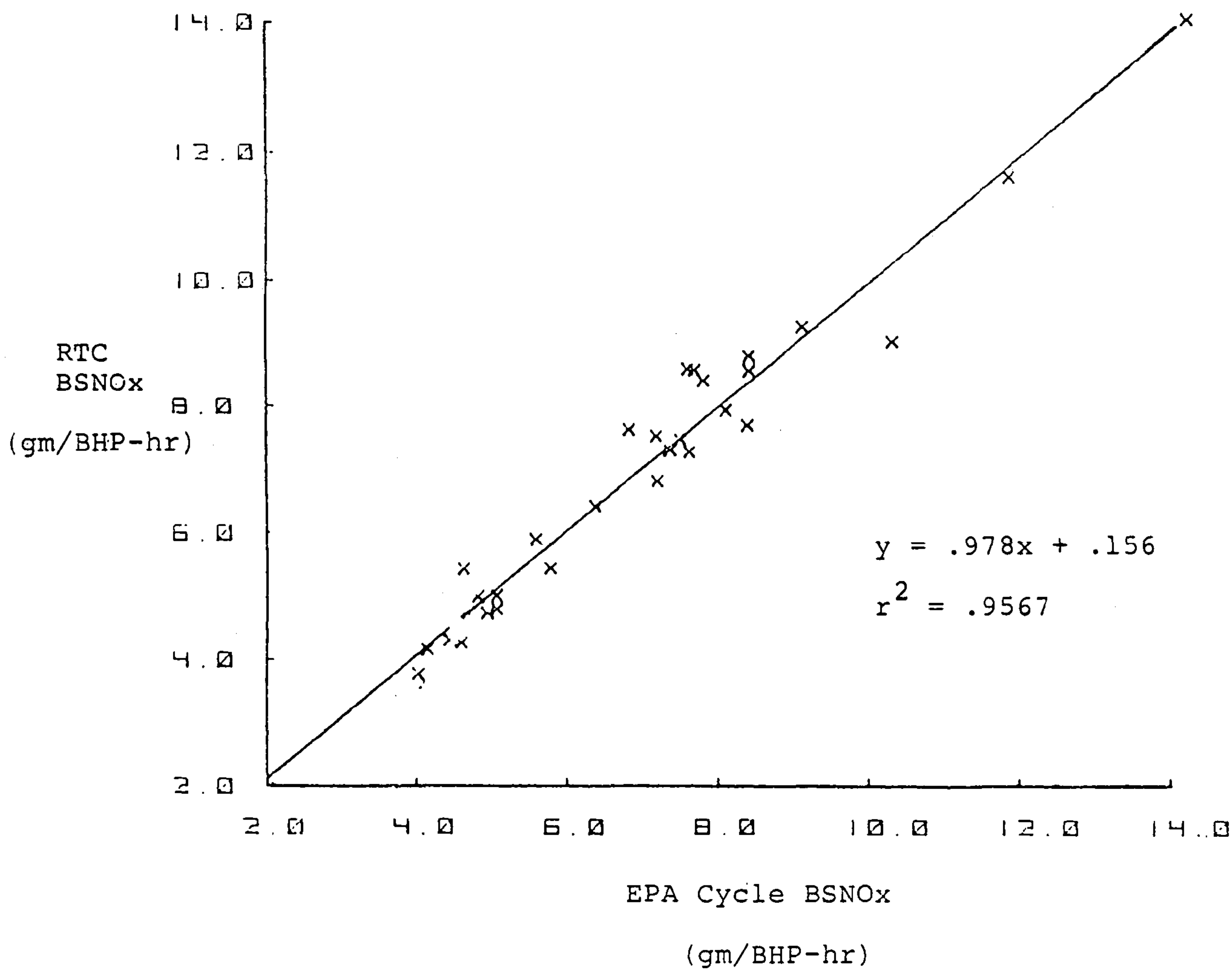
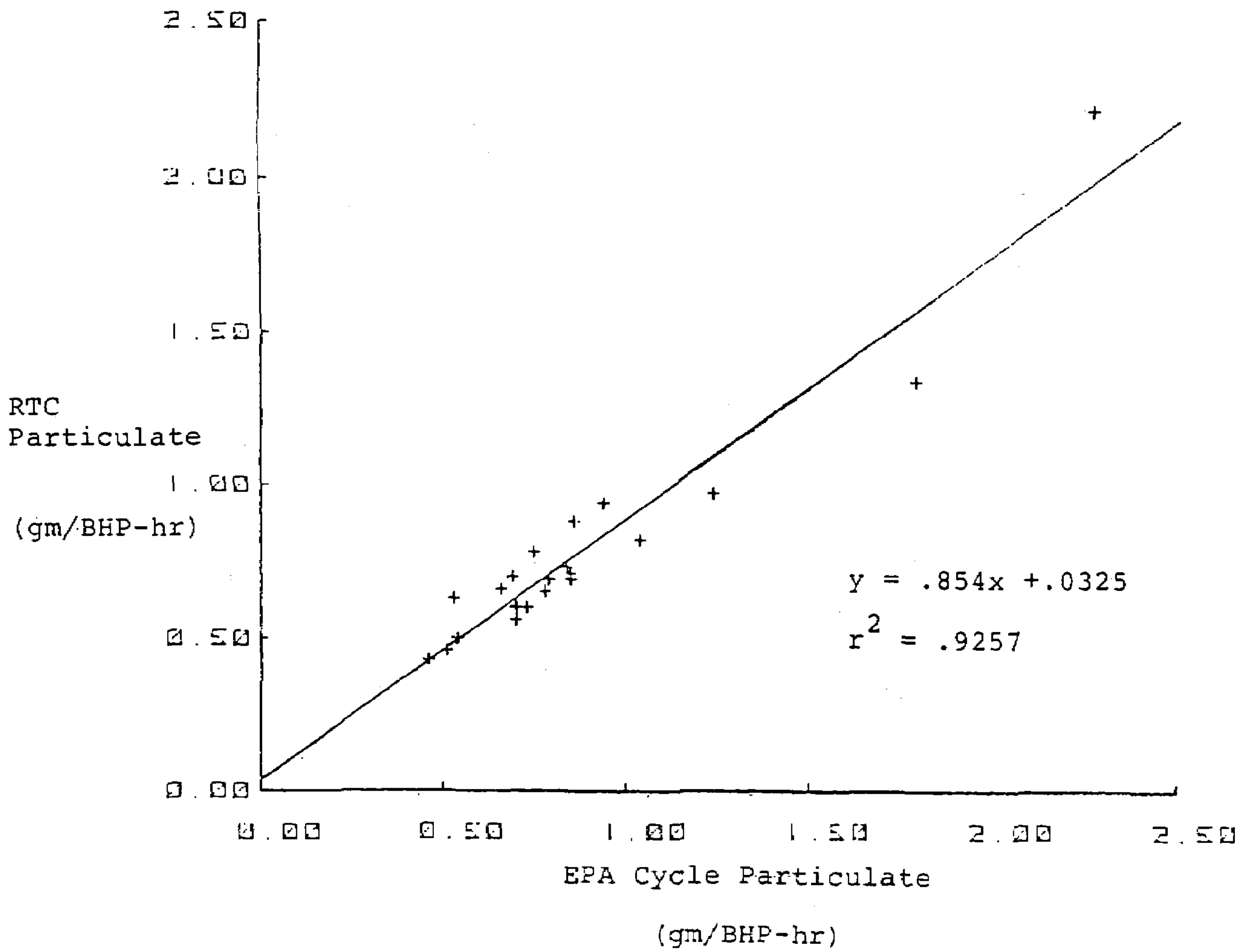


FIGURE 5-3

RTC vs. EPA Cycle Particulate Emissions



statutory standard and level typical of current technology diesels.

4. Economic Impact

It should be noted that the choice of test cycle is a technical issue, not an economic issue. The cost of operating a transient test is essentially unaffected by the driving cycle itself. Also, the emission control strategy for a given engine should not vary with the test cycle if the level of standards for given cycles reflect equivalent stringency and the cycles exercise the engine in fundamentally the same way.

C. Conclusions

1. Most diesel engine manufacturers support, or at least would not oppose, the RTC as a certification test option. Inclusion of the NYF segment in the RTC cycle makes the RTC somewhat more representative of the entire CAPE-21 data base than the EPA cycle.

2. The RTC is statistically comparable to the EPA cycle. The most important differences are that the work over the RTC is higher than the EPA cycle, and with the RTC the engine is operated over the highest power LAF segment of the cycle sooner into the test.

3. Data from 30 engine configurations indicate that at the level of the standards, HC emissions are 15.3 percent lower on the RTC, and NOx emissions are 1.0 percent lower on the RTC. These differences in measured emissions arise, most likely, from the differences in engine work between the cycles. The emissions results from the RTC correlate extremely well with EPA cycle results, and both cycles can be expected to accurately predict in-use emission reductions. Emission standards for the RTC, adjusted to levels of equivalent stringency as the emission standards for the EPA cycle, have been calculated to be:

Cycle	HC (g/BHP-hr)	NOx (g/BHP-hr)
EPA	1.30	10.7
RTC	1.10	10.6

4. The RTC appears to be an acceptable option for certification testing as long as the standards are adjusted to reflect equivalent stringency. This precludes the arbitrary relaxation of in place emission standards by test procedure change. Retention of the EPA test as an option would also

guarantee that no increase in statutory standard stringency is forced by inaccurately derived offsets, both on an average, or on an engine-specific basis. Finally, use of both tests as options would allow further comparative testing between cycles. In the future, the use of only one test for certification would be the simplest and the preferable approach.

5. The choice of test cycles is a technical, not an economic issue. Relief to the manufacturers at this point in time with respect to alternate test cycles will have no effect economically. Accepting alternate cycles as options fully addresses industry's technical concerns.

References

1. Derived from Comments Submitted to EPA Public Docket No. A-81-20.

2. Derived from Comments Submitted to EPA Public Docket No. A-81-11.

3. "Evaluation of the Federal Test Procedure for Heavy-Duty Diesel Engines for 1984 and the Development of the Real Time Test Cycle," W. L. Brown, Jr., Research Report 88-29, File 18967, Caterpillar Tractor Company, June 22, 1981.

4. "Transient Cycle Arrangement for Heavy-Duty Engine and Chassis Emission Testing," Chester J. France, EPA Report HDV 78-04, August 1978.

CHAPTER 6

THE MVMA CYCLE: AN ALTERNATE HEAVY-DUTY GASOLINE ENGINE DRIVING CYCLE

The Motor Vehicle Manufacturers Association (MVMA) has developed an alternative heavy-duty gasoline engine driving cycle and has proposed it be used as a complete replacement for the EPA cycle for certification testing. The MVMA cycle was developed because of concern about the representativeness of the EPA cycle. In this chapter the industry recommendations, cycle development, statistical and emissions analyses, and economic impact concerning the use of the MVMA cycle as a test alternative are discussed.

I. Summary of Comments[1,2]

MVMA and member manufacturers have submitted specific recommendations with regards to the MVMA cycle as a test alternative to the EPA cycle. These recommendations are summarized below.

MVMA - MVMA recommends EPA adopt the MVMA cycle in lieu of the EPA cycle for certification testing. MVMA also recommends an interlaboratory correlation program be initiated to determine and remedy any deficiencies.

Chrysler - Since Chrysler does not have transient testing facilities, it has no experience with the MVMA cycle. Chrysler, therefore, has not made specific recommendations on the use of MVMA cycle.

Ford - Ford recommends the MVMA cycle be adopted instead of the EPA cycle for certification testing. Ford also believes an interlaboratory correlation program should be conducted.

General Motors - GM recommends that EPA adopt the MVMA cycle as a replacement for the EPA cycle. GM also recommends that an EPA/Industry cooperative study be initiated to determine if interlaboratory correlation exists and to address other test procedural concerns.

International Harvester - Since IHC is deemphasizing the gasoline engine segment of its market, it has not been following the MVMA cycle developments and does not have specific comments.

II. Analysis of Comments

In this analysis, we address the technical adequacy, representativeness, and relative stringency of the MVMA cycle.

A. Cycle Development[3]

The MVMA heavy-duty gasoline engine driving cycle was developed because of industry concerns that the EPA cycle was inadequate in the following two areas:

1. It was not representative of real world truck operation.

2. The irregular nature of the cycle could create interlaboratory correlation problems.

In an attempt to alleviate some of these concerns, MVMA modified the EPA cycle to obtain a driving cycle which they felt was more representative and more acceptable. MVMA established four basic objectives for constructing the modified test cycle. The modified cycle had to:

1. Maintain the general character of the EPA cycle.

2. Improve the relationship between simultaneous speed, power, and acceleration.

3. Reduce momentary speed excursions.

4. Reduce excessive throttle manipulations.

To accomplish these objectives, the cycle was simply examined on a second-by-second basis; using engineering judgment, the speed and torque specifications were revised where it was deemed appropriate. The resulting driving cycle was a smoothed version of the EPA cycle with a revised synchronization between speed and torque commands. Technical justifications for specific cycle changes were not submitted by MVMA. EPA was merely presented with the cycle and the claim that it represents MVMA's best engineering judgment. Unlike the Real Time Cycle alternative, in-depth documentation of the MVMA cycle development methodology was not provided to EPA.

B. Statistical Analysis

A comparison of overall statistical parameters from the MVMA cycle, EPA cycle, and the CAPE-21 data base is listed in Table 6-1. The CAPE-21 statistics are included for comparison purposes, although the MVMA cycle was not directly derived from the CAPE-21 data base.

As can be seen from the table, the EPA cycle and MVMA cycle are very similar statistically, with respect to speed and torque parameters. There are no major discrepancies, which is to be expected since the MVMA driving cycle is directly derived from the EPA cycle. However, data from engine tests indicate

Table 6-1

Cycle Statistics:MVMA Cycle,
EPA Cycle, CAPE-21 Data Base

Parameter	MVMA	EPA	CAPE-21
Torque			
Mean (%)	37	36	34
Percent of Cycle Time			
Accel (%)	15	17	15
Decel (%)	19	20	16
Cruise (%)	28	26	28
Motor (%)	9	10	13
Idle (%)	28	27	28
RPM			
Mean (%)	31	30	31
Percent of Cycle Time			
Accel (%)	20	24	20
Decel (%)	26	21	26
Cruise (%)	26	23	26
Idle (%)	28	31	28

total engine work (BHP-HR) over the MVMA cycle is about 10 percent higher than on the EPA cycle. This increase in cycle work is attributed to the resynchronization of the speed and torque commands so there are more events where speed and torque are increasing or decreasing at the same time, resulting in increased integrated power-hr. Another important difference is that the MVMA cycle is less transient than the EPA cycle. The speed and torque sequences are smoother and numbers of torque accelerations have been completely eliminated, reducing the frequency of throttle position changes for engine operation (reducing accelerator pump operation and transient fuel enrichment). In summary, the MVMA cycle is statistically similar to the EPA cycle, but as explained in greater detail below, not operationally identical.

3. Emissions Analysis

EPA, Ford, and GM have to date tested a small number of gasoline engines and configurations to compare emissions results on the MVMA cycle and the EPA cycle. The emissions data from these tests are summarized in Table 6-2 and plotted in Figures 6-1, 6-2, and 6-3 with their accompanying regression lines. A total of 12 engines/configurations are included.

Excellent statistical correlations were observed between the MVMA cycle and the EPA cycle; for emissions of HC, CO and NOx, values of r^2 were .97, .98, and .93 respectively. Definite emissions offsets were also observed. The MVMA cycle HC emissions offset averaged -21.32 percent from the EPA cycle with a range of -44 percent to +13 percent and coefficient of variation of .724; the CO emissions offset averaged -7.45 percent with a range of -24 percent to +9 percent and coefficient variation of 1.27; and the NOx emissions offset averaged .98 percent with a range of -4.2 percent to +10.1 percent and coefficient of variation of 4.64. As indicated by the regression lines, the percentage emissions offsets between cycles increase as absolute emission levels decrease.

The HC and CO emissions differences are explainable by the operational differences between the cycles. The most significant differences between the MVMA cycle and the EPA cycle are that the MVMA cycle is smoother, and that the speed and torque commands follow each other more closely on the MVMA cycle (resulting in an increase in integrated power-hour). These changes are illustrated graphically in Figure 6-4 where the same characteristic sections from both test cycles have been overlaid. The decrease in the transience of the MVMA cycle will result in less movement of the engine accelerator pump, which could be expected to result in lower HC and CO emissions.

The degree to which the cycle smoothing explains the observed emission differences, however, is unknown. The

Table 6-2

Summary of Emissions Data EPA Cycle vs. MVMA Cycle

Engine	Tested by	Cycle	Number and Type of Tests	HC (g/BHP-hr)	CO (g/BHP-hr)	NOx (g/BHP-hr)
1969 GM 292	EPA	EPA	3CS,5HS	6.12	118.4	6.54
1969 GM 292	EPA	MVMA	2CS,5HS	4.72	109.4	6.38
% Difference				-22.88%	-7.6%	-2.45%
1969 Ford F300	EPA	EPA	2CS,4HS	7.64	126.64	7.74
1969 Ford F300	EPA	MVMA	2CS,4HS	6.49	124.99	7.50
% Difference				-15.05%	-1.32%	-3.10%
1969 GM 350	EPA	EPA	2CS,5HS	8.14	135.53	4.43
1969 GM 350	EPA	MVMA	2CS,5HS	7.71	143.15	4.22
% Difference				-5.60%	5.62%	-4.74%
Ford 4.9L	Ford	EPA	2CS,2HS	2.86	28.4	8.04
Ford 4.9L	Ford	MVMA	1CS,1HS	2.40	21.7	8.75
% Difference				-16.08%	-23.59%	8.83%
Ford 6.1L [a]	Ford	EPA	1CS,1HS	2.36	28.9	7.42
Ford 6.1L I	Ford	MVMA	1CS,1HS	1.50	27.8	6.67
% Difference				-36.44%	-3.81%	10.11%
Ford 6.1L II[a]	Ford	EPA	2CS,4HS	2.46	30.5	8.29
Ford 6.1L II	Ford	MVMA	2CS,6HS	1.59	25.7	8.01
% Difference				-35.37%	-15.74%	3.38%
Ford 6.1L III[a]	Ford	EPA	1CS,3HS	3.28	31.3	8.55
Ford 6.1L III	Ford	MVMA	1CS,3HS	1.81	27.7	8.77
% Difference				-44.82%	-11.50%	2.57%

Table 6-2 (cont'd)

Summary of Emissions Data EPA Cycle vs. MVMA Cycle

Engine	Tested by	Cycle	Number and Type of Tests	HC (g/BHP-hr)	CO (g/BHP-hr)	NOx (g/BHP-hr)
Ford 6.1L IV[a]	Ford	EPA	1CS,1HS	2.34	30.6	8.17
Ford 6.1L IV	Ford	MVMA	1CS,1HS	1.48	25.5	8.04
% Difference				-36.75%	-16.67%	-1.59%
1981 454	GM	EPA	1CS,1HS	1.28	47.9	5.06
1981 454	GM	MVMA	1CS,1HS	1.44	52.4	4.91
% Difference				12.50%	9.39%	-2.96%
1981 454 less controls	GM	EPA	1CS,1HS	3.12	98.7	5.48
1981 454 less controls	GM	MVMA	1CS,1HS	2.89	100.4	4.25
% Difference				-7.37%	1.72%	-4.20%
1981 427	GM	EPA	1CS,HS	7.45	63.4	6.22
1981 427	GM	MVMA	1CS,HS	5.85	52.9	6.47
% Difference				-21.48%	-16.56%	4.02%
1981 427 less controls	GM	EPA	1CS,1HS	10.06	129.6	5.67
1981 427 less controls	GM	MVMA	1CS,1HS	8.51	116.0	5.93
% Difference				-15.41%	-10.49%	4.59%
1981 292	GM	EPA	1CS,1HS	3.33	26.7	8.13
1981 292	GM	MVMA	1CS,1HS	2.70	26.3	8.11

Table 6-2 (cont'd)

Summary of Emissions Data EPA Cycle vs. MVMA Cycle

Engine	Tested by	Cycle	Number and Type of Tests	HC (g/BHP-hr)	CO (g/BHP-hr)	NOx (g/BHP-hr)
% Difference				-18.92%	-1.50%	-.25%
1984 292 prototype	GM	EPA	1HS	1.66	12.3	8.93
1984 292 prototype	GM	MVMA	1HS	1.08	10.8	8.89
% Difference				-34.94%	-12.2%	-.45%

$$\% \text{ Differences} = \frac{\text{MVMA} - \text{EPA}}{\text{EPA}}$$

[a] Unique hardware and/or calibration.

FIGURE 6-1

EPA Cycle vs. MVMA Cycle BSHC Emissions

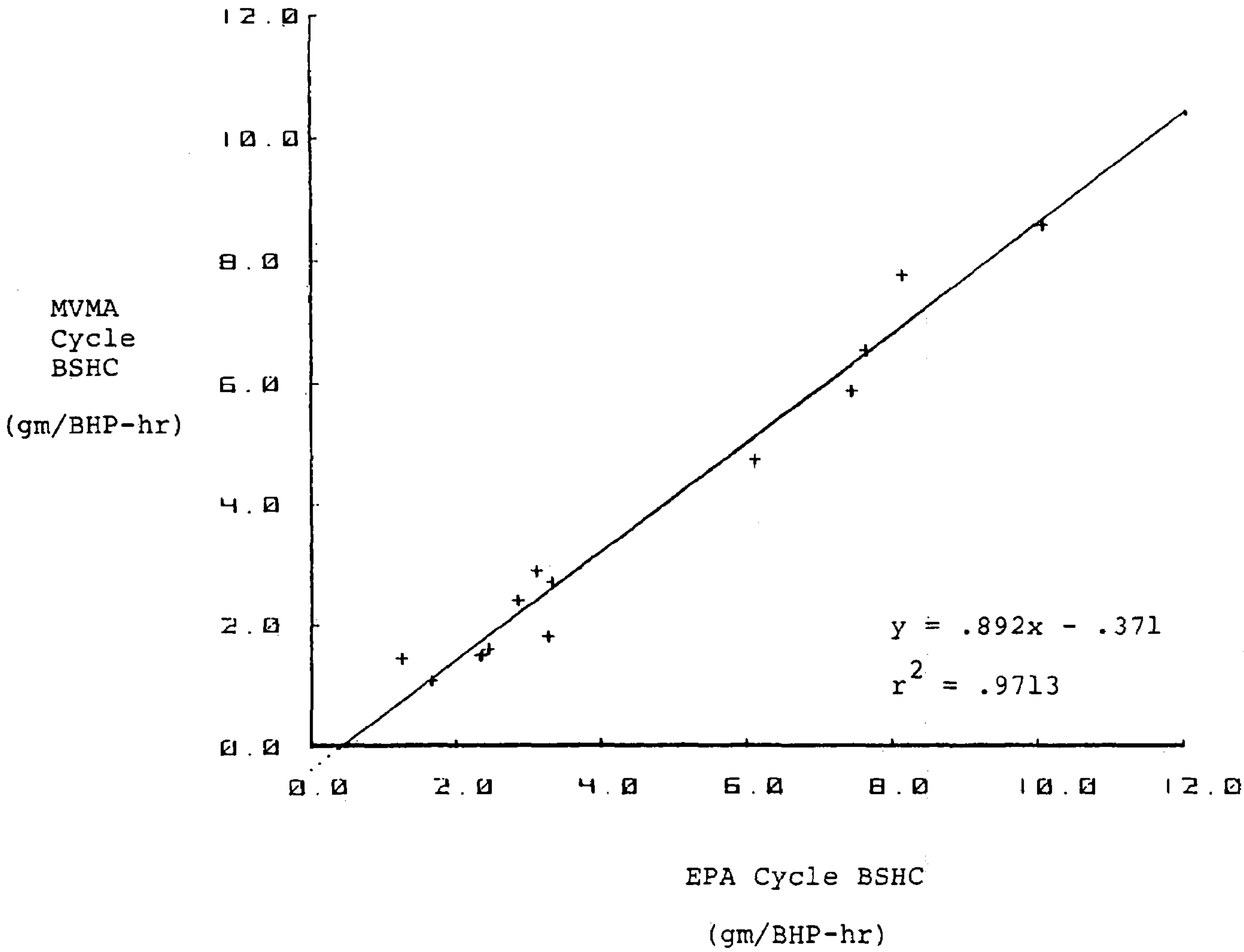


FIGURE 6-2

EPA Cycle vs. MVMA Cycle BSCO Emissions

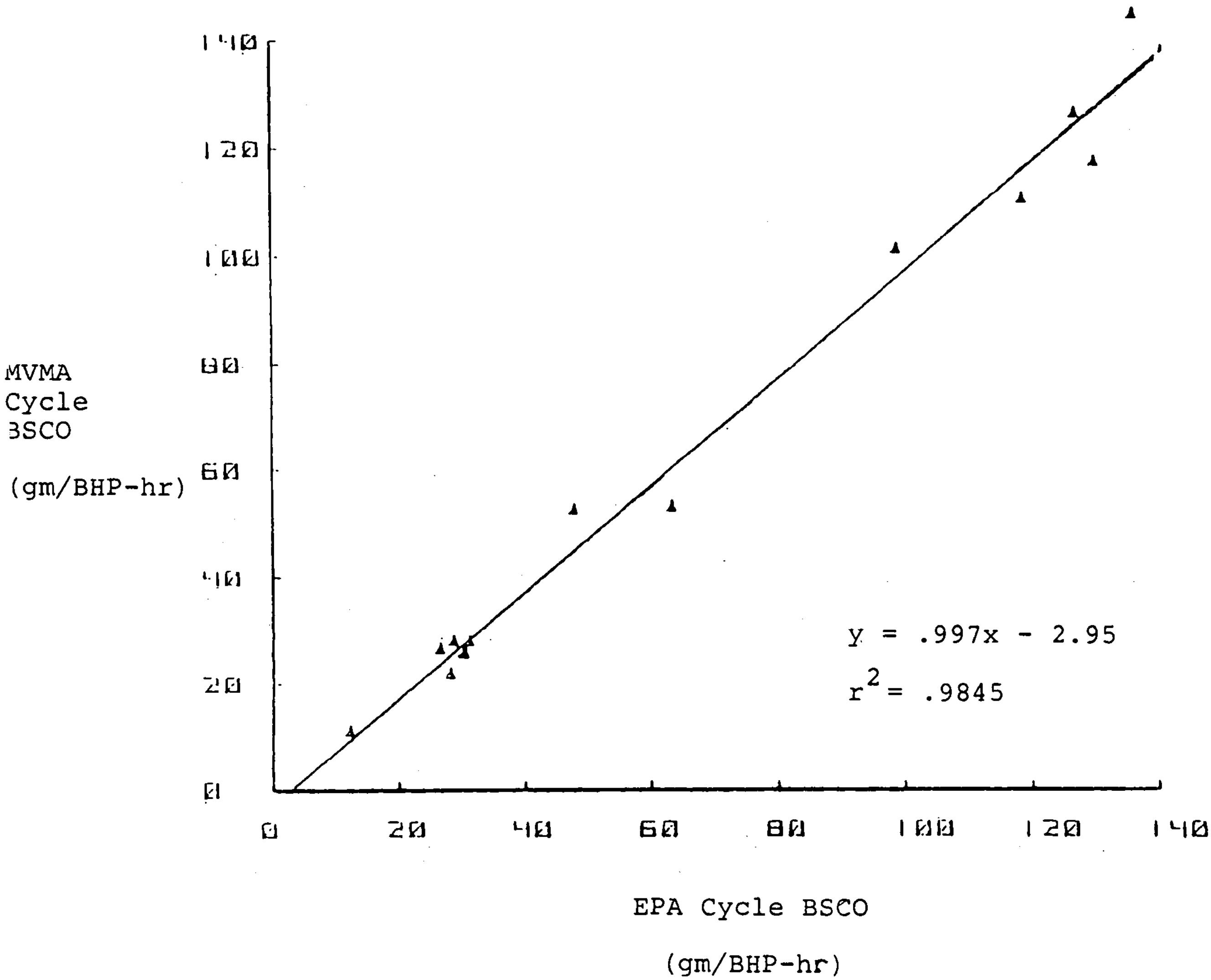


FIGURE 6-3

EPA Cycle vs. MVMA Cycle BSNOx Emissions

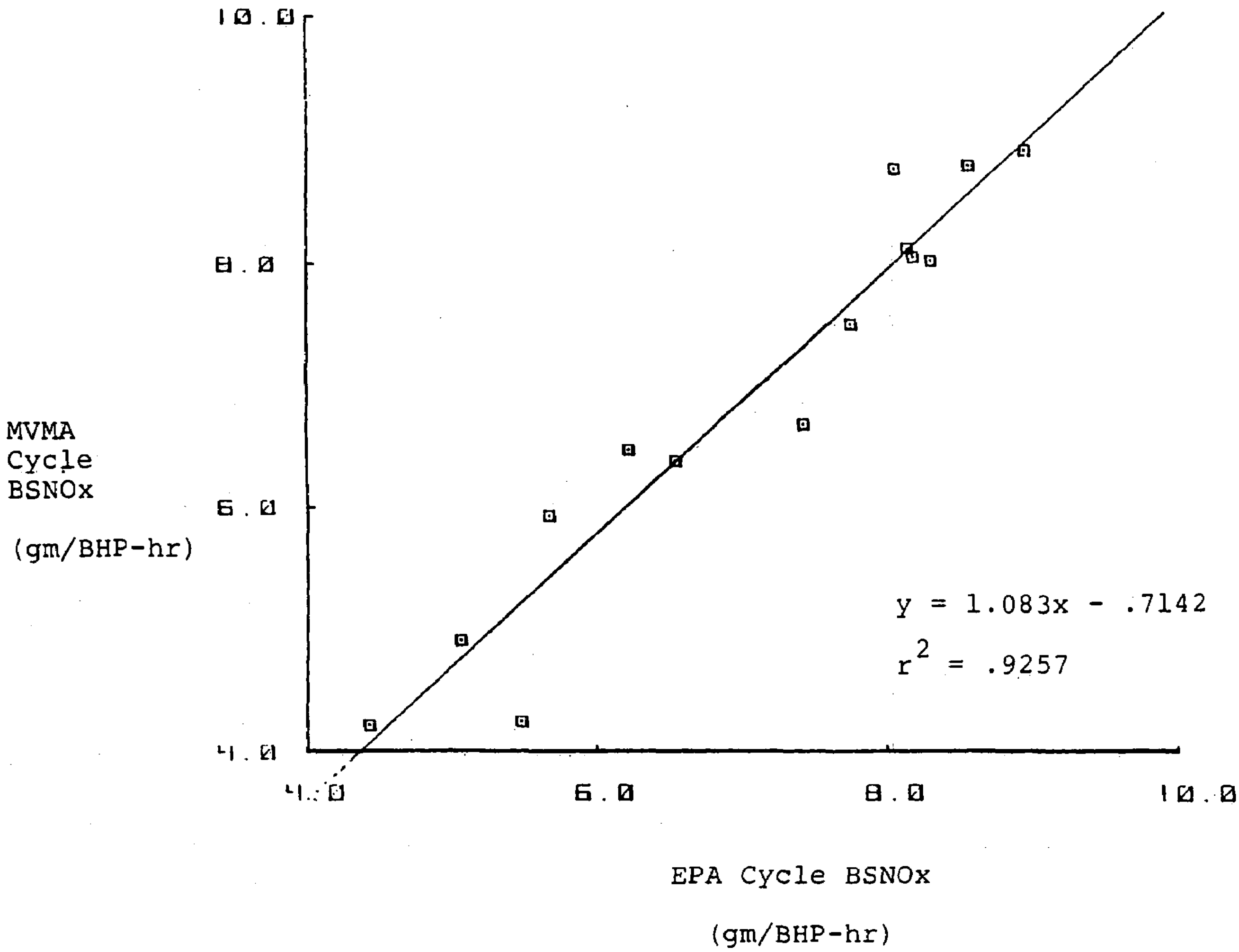
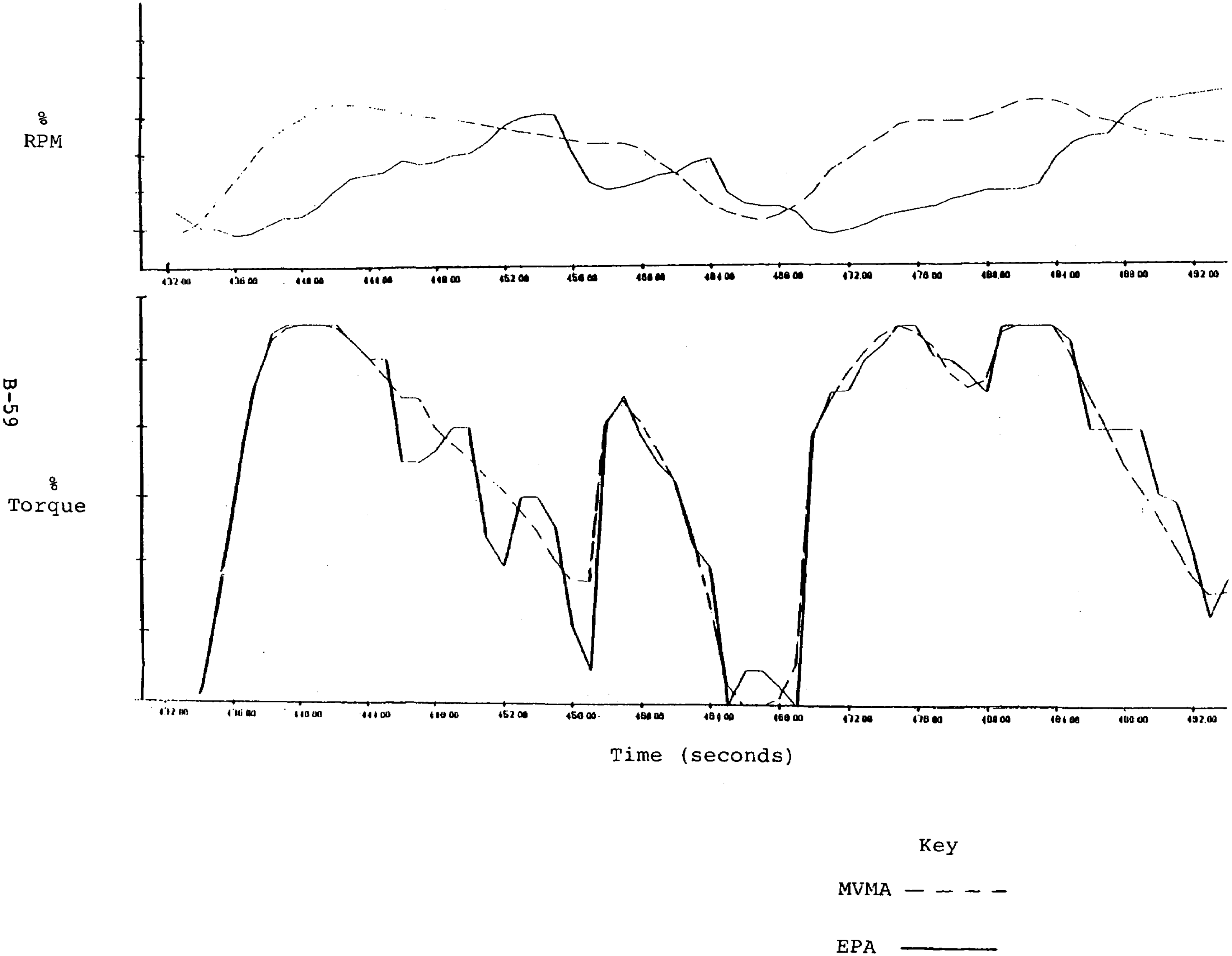


FIGURE 6-4

MVMA Cycle and EPA Cycle Comparison



difference in transience of the MVMA cycle and EPA cycle has not been quantified, and previous data (see Chapter 4) indicated that a decrease in transient operation resulting from dampening of the throttle controller had no effect on emissions.* The rephasing of the speed and torque commands results in different modes (combination of speed and torque) of engine operation on the two test cycles, with fewer events at both lower speed and load on the MVMA cycle. The observed increase in power-hour over the MVMA cycle may also explain the decrease in the specific emissions (i.e., more emissions divided by increased output work). This may contribute to the lower BSHC and BSCO emissions on the MVMA cycle, although the effect has not been quantified. Changing the engine speed at which motoring (defined as -10 percent maximum engine torque) occurs may also explain emission differences between the cycles. Ford has mentioned the possibility of modal and subcycle testing[2] to help understand emissions offsets between the two cycles. This type of information would be beneficial and its acquisition is encouraged.

The MVMA cycle does not yield emissions equivalent to the EPA driving cycle, i.e., it is not equivalently stringent at the same numerical emission standards for HC and CO. The MVMA cycle does, however, correlate well with the EPA cycle for the different engines tested to date. A strong correlation between an alternate test cycle and the EPA cycle implies that there is no advantage in using one cycle over the other as long as the emission standards reflect equivalent stringency.

The MVMA cycle HC and CO standards have been adjusted to levels of equivalent stringency as the EPA cycle by substituting EPA cycle standards in the least squares regression lines from Figures 6-1 to 6-3. The standards are summarized below:

	HC(g/bhp-hr)	CO(g/bhp-hr)	NOx(g/bhp-hr)
1984 EPA Cycle	1.3	15.5	10.7
1984 MVMA Cycle	0.8	12.5	10.9

1984 statutory emission standards based upon the MVMA cycle would, therefore, be .8 g/BHP-hr HC, 12.5 g/BHP-hr CO, and 10.9 g/BHP-hr NOx. Interim revised standards would be adjusted in an identical manner. (For example, the proposed revised EPA standards of 1.3/35.0 would be equivalent to MVMA cycle standards of .8/31.9.)

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* There is perhaps a significant difference between mechanically smoothing accelerations (as was done by EPA's sensitivity testing) and completely eliminating accelerations (as was done by MVMA).

This method of standard adjustment results in large percentage differences (38 percent HC, 19 percent CO) between the MVMA cycle and the statutory EPA cycle standards. A large difference in cycle standards is appropriate if the MVMA cycle is indeed significantly more lenient than the EPA cycle. Futhermore, it is not known how the operational differences between the MVMA and EPA cycles would affect compliance strategies. For example, the CO emissions difference between test cycles for the Ford 6.1 liter engine (see Table 6-2) varied from 1.1 g/bhp-hr (4 percent difference) to 5.1 g/bhp-hr (17 percent difference) with calibration and/or hardware changes, indicating that the MVMA cycle may be more amenable to a given emission control strategy. However, the data on which this analysis is based are limited to 14 configurations of 8 different engines, including three 1969 baseline engines. More testing will be required to more confidently determine the emissions differences between cycles at the level of the emission standards, and more adequately characterize the MVMA test cycle.

D. Economic Impact

As was discussed in Chapter 5, the choice of test cycles will not have an effect economically. The cost of operating a transient test is unaffected by the driving cycle itself, assuming the standards are adjusted to levels of equivalent stringency to the EPA cycle, and the cycles exercise the engine in fundamentally the same way. The choice of test cycles is a technical, not an economic issue.

III. Conclusions

A. MVMA and its members who are most significantly affected, Ford and GM, recommend the MVMA cycle be used for certification testing instead of the EPA cycle. They also recommend an EPA/Industry cooperative test program be initiated.

B. The MVMA cycle is statistically comparable to the EPA cycle. The most significant differences are that the speed and the torque sequence is smoother, total engine work (BHP-hr) is higher on the MVMA cycle, and the speed and torque cycles have been rephased with each other.

C. Data from 14 engines/configurations indicate that, at the level of the standards, HC emissions are 38.5 percent lower on the MVMA cycle, CO emissions are 19.3 percent lower on the MVMA cycle, and NOx emissions are 1.9 percent higher on the MVMA cycle. However, the sample size may be too small to accurately assess the emissions differences for all gasoline engines. Conclusions based upon this data alone should be regarded as tentative until more engine testing, such as an EPA/Industry test program, can be conducted.

D. The MVMA cycle may be an acceptable <u>option</u> for certification testing. However, the undocumented and perhaps arbitrary method of MVMA cycle generation gives us less assurance of its overall adequacy relative to EPA's cycle. This caution is warranted both by the very small data base at present, and also by the data presented above, in which engine recalibrations can yield significantly greater emission reductions on the MVMA cycle than the EPA cycle. These facts argue for more comparative testing before the MVMA cycle can be judged to be an equivalent option to the EPA cycle.

References

1. Derived from Comments Submitted to EPA Public Docket No. A-81-20.

2. Derived from Comments Submitted to EPA Public Docket No. A-81-11.

3. MVMA-Modified Heavy-Duty Gasoline Engine Transient Emission Test Cycle, Attachment, Letter to EPA Administrator, Motor Vehicle Manufacturers Association, Feb. 15, 1982. (See EPA Public Docket No. A-81-11, IV-D-2 and IV-D-2a.)

CHAPTER 7

THE DIESEL TRANSIENT TEST/13-MODE OPTION

I. Summary of Comments

Diesel engine manufacturers again questioned the need for an expensive transient test for diesel engines. Several manufacturers and the EMA submitted emission data to argue that a sufficient correlation exists between the 13-mode steady-state and EPA's transient test for regulated pollutants. In addition, the manufacturers argued for a more extensive steady-state option for 1984 and later years than the single-year option represented by the 0.5 g/BHP-hr optional 13-mode HC standard which EPA originally provided.

II. Analysis of Comments

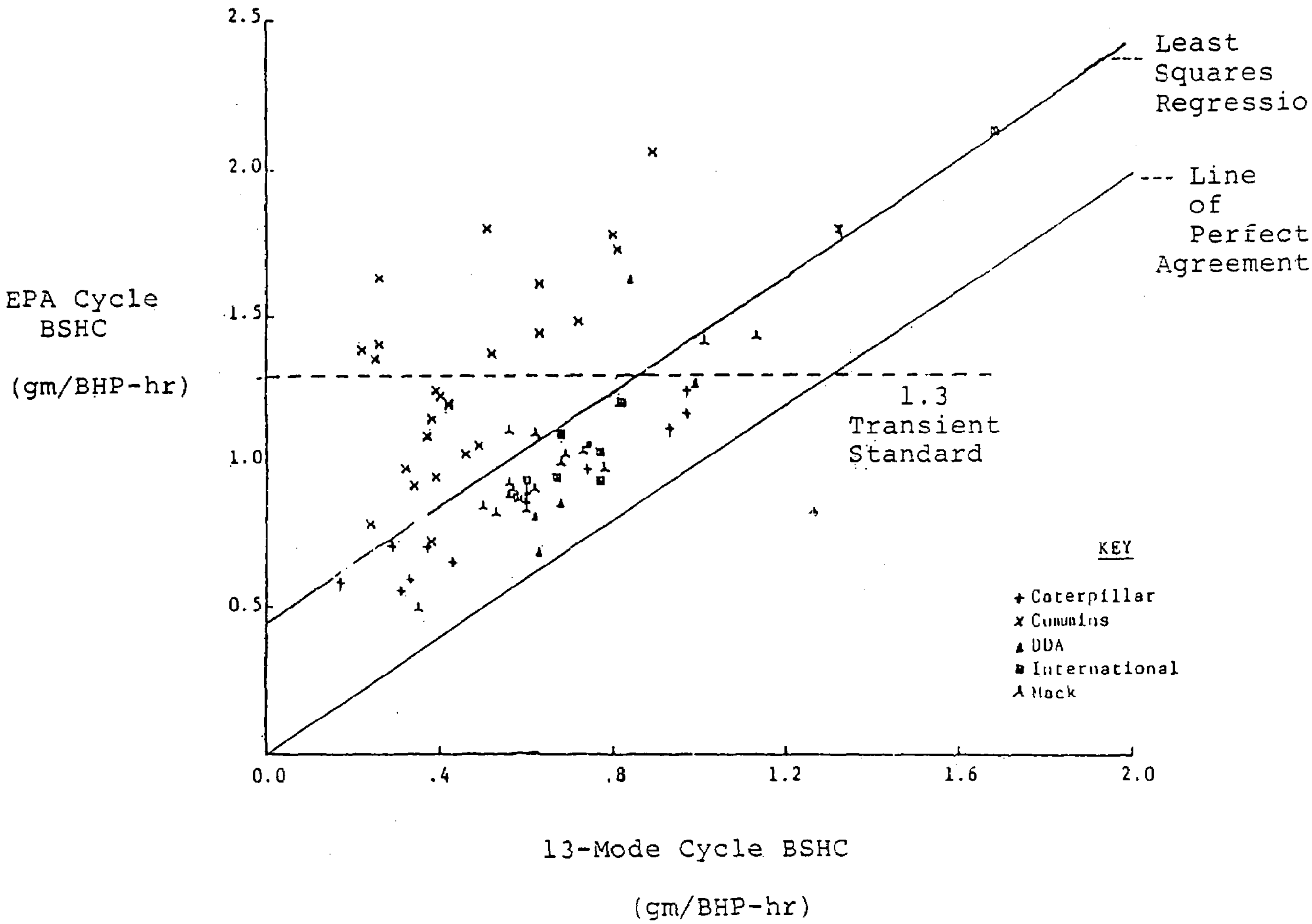
Figures 7-1, 7-2, and 7-3 present available comparative emission data for the 13-mode and EPA transient tests. In no cases were the regression lines "forced" through zero--as were many of the regression analyses performed by the industry. Not only is the zero-zero point a physically meaningless point of singularity, it is incorrect statistical practice to arbitrarily force data through any non-data point. This causes the correlation to appear much better than it actually is. Such is the case with the industry's analyses.

Compiling all data submitted by the industry,[1] all data taken by EPA and Southwest Research,[2] and all available data from the EPA/EMA Round Robin Program,[3] EPA evaluated the correlation between tests. For BSHC, the least squares regression line had an r^2 value of .51, with an intercept of .45 g/BHP-hr. For BSNOx, and BS particulate emissions, the calculated values were .72/2.1 and .73/.34 respectively.

At current levels of BSHC (both above and below the statutory transient standard of 1.3 g/BHP-hr), the correlation between transient and steady-state test procedures is poor. Only 51 percent of the variation in a transient result is explainable by a variation in a 13-mode result, i.e., the 13-mode is a poor predictor of transient BSHC. This is indicated most clearly by the dramatic scatter of data presented in Figure 7-1. Note that 13-mode results as low as .5 g/BHP-hr are found on several engines whose corresponding transient results exceed the 1.3 g/BHP-hr transient standard. At current levels of NOx emissions, however, the 13-mode is a better but not good predictor of transient emissions. (See Figure 7-2.) We note that this "correlation" exists at levels of emissions which represent little applied emission control. EPA's earlier analysis of the justification for a transient test[4] indicated that steady-state tests traditionally become ineffective as technology is applied to achieve substantial

FIGURE 7-1

Comparative Transient vs. 13-Mode HC Emissions

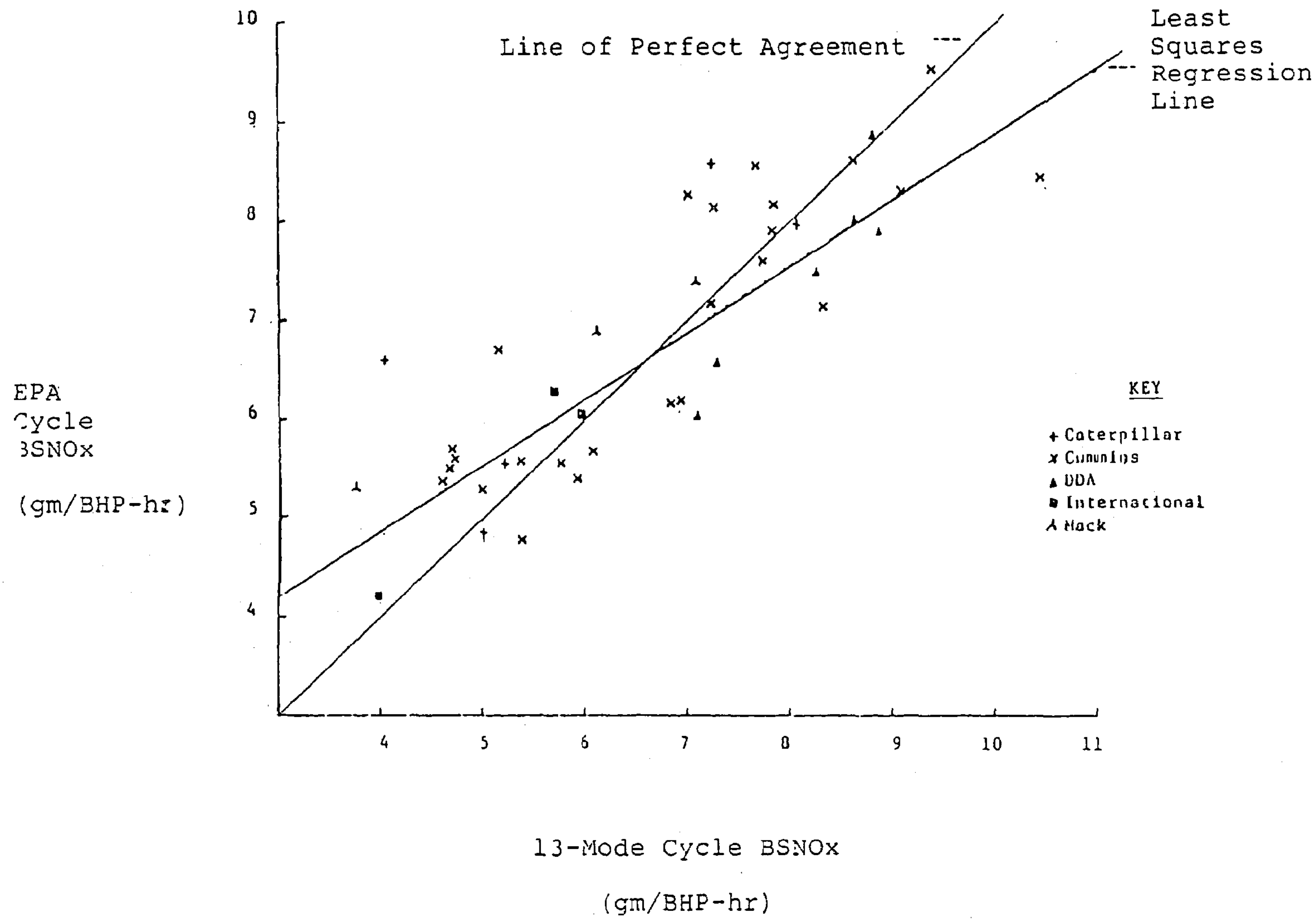


Regression Line Equation: $y = .96x + .449$

$r^2 = .514$

FIGURE 7-2

Comparative Transient vs. 13-Mode Emissions for NOx

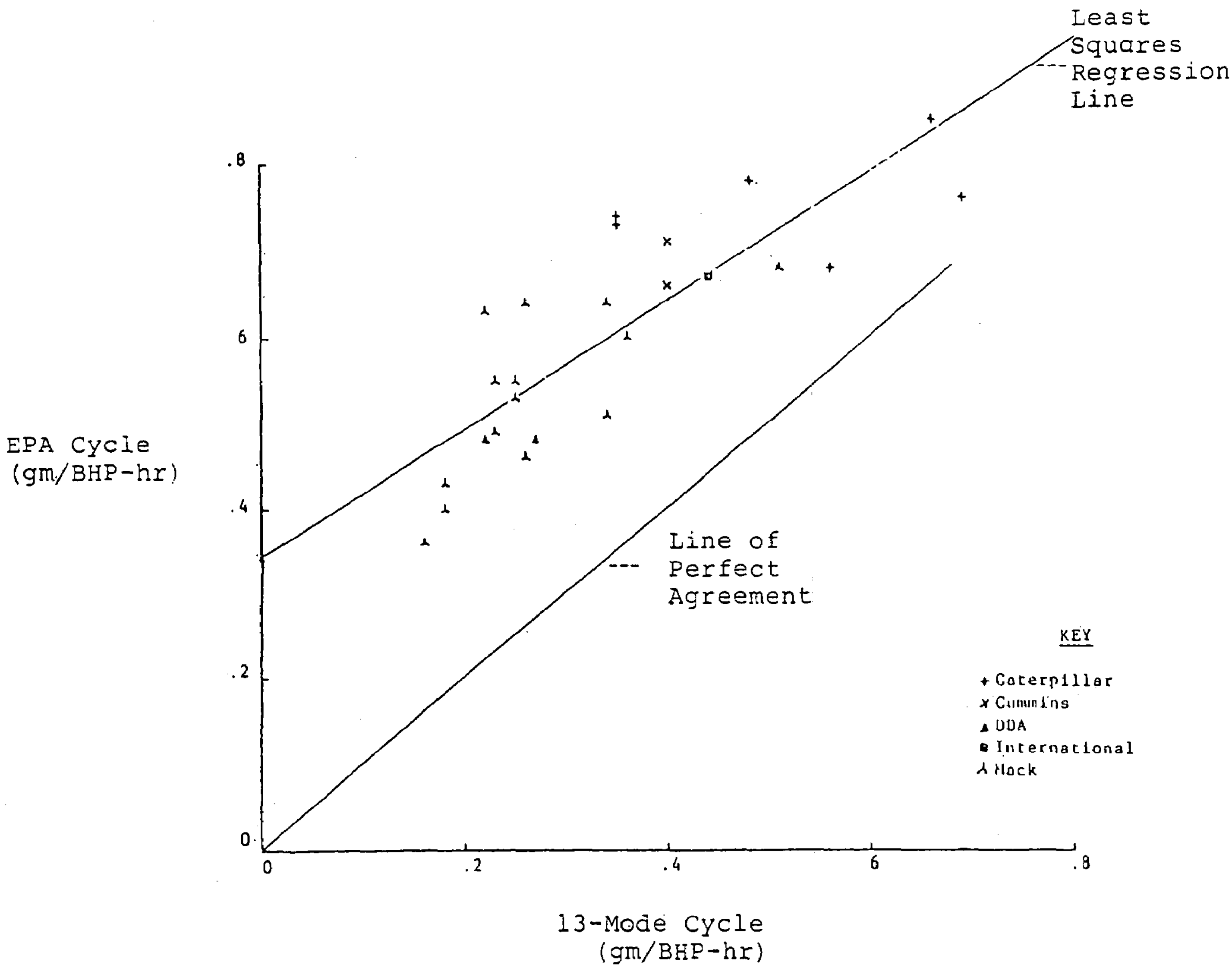


Regression Line Equation: $y = .685x + 2.085$

$r^2 = .722$

FIGURE 7-3

Comparative Transient vs. 13-Mode Particulate Emissions



Regression Line Equation: $y = .758x + .342$

$r^2 = .728$

emission reductions. This is also true of the "correlation" between transient and steady-state particulates (see Figure 7-3) for which future standards will also be promulgated. The promulgation of more stringent standards (NOx and particulate) makes the use of the transient test all the more necessary to ensure that laboratory emission reductions also occur in the field. Using all available emission data, we find that the transient test is technically justifiable today, and even moreso when more stringent NOx and particulate standards become applicable.

This justification did not prevent EPA from originally providing a steady-state option for 1984 for heavy-duty diesel engines. EPA's rationale was to allow time for the industry to investigate the use of existing eddy-current dynamometers, and perhaps save money on facility conversion. The optional 0.5 g/BHP-hr HC standard was set to minimize the possibility that no compromise in engine emissions would result (relative to the 1.3 transient standard), although EPA has previously stated that the standard was intended to be approximately as stringent as the transient standard and to not require extensive development work. It now appears that a single year option would effectively spread transient recertification requirements out over two model years, as our leadtime analysis in Chapter III indicates is necessary for the diesel manufacturers.

The industry has argued that a 0.5 g/BHP-hr optional 13-mode standard is too stringent, and is essentially a non-option.[1,5] As indicated by Figure 7-4 (representing the HC emission distribution of all domestic and foreign HD diesel engines certified in 1982 on the 13-mode test), as the optional 13-mode standard becomes more stringent, fewer engines can be carried over without development work and recertification. Figure 7-4 indicates that with a 0.5 standard and a full useful life, 21 percent (13/67) of 1982 engine families would be eligible for carryover. Revising the optional standard to the industy's recommended 1.0 g/BHP-hr permits 73 percent (46/67) of 1982 engine families to carryover. This would certainly provide increased flexibility for allocation of testing and development resources for both model years 1984 and 1985. (We note that these percentages do not include engines which can still be recertified on the 13-mode test in 1983, and then be eligible for carryover.) In short, EPA's acceptance of the industry's recommended optional standard would alleviate much of the recertification testing burden for 1984.

Based upon the correlation presented in Figure 7-1, however, we have little confidence that any 13-mode standard between 0.5 and 1.3 can adequately predict compliance with a 1.3 transient standard; hence, its level should be set based upon the industry's requirements for relief, not upon emission control requirements. A steady-state HC standard of 1.0

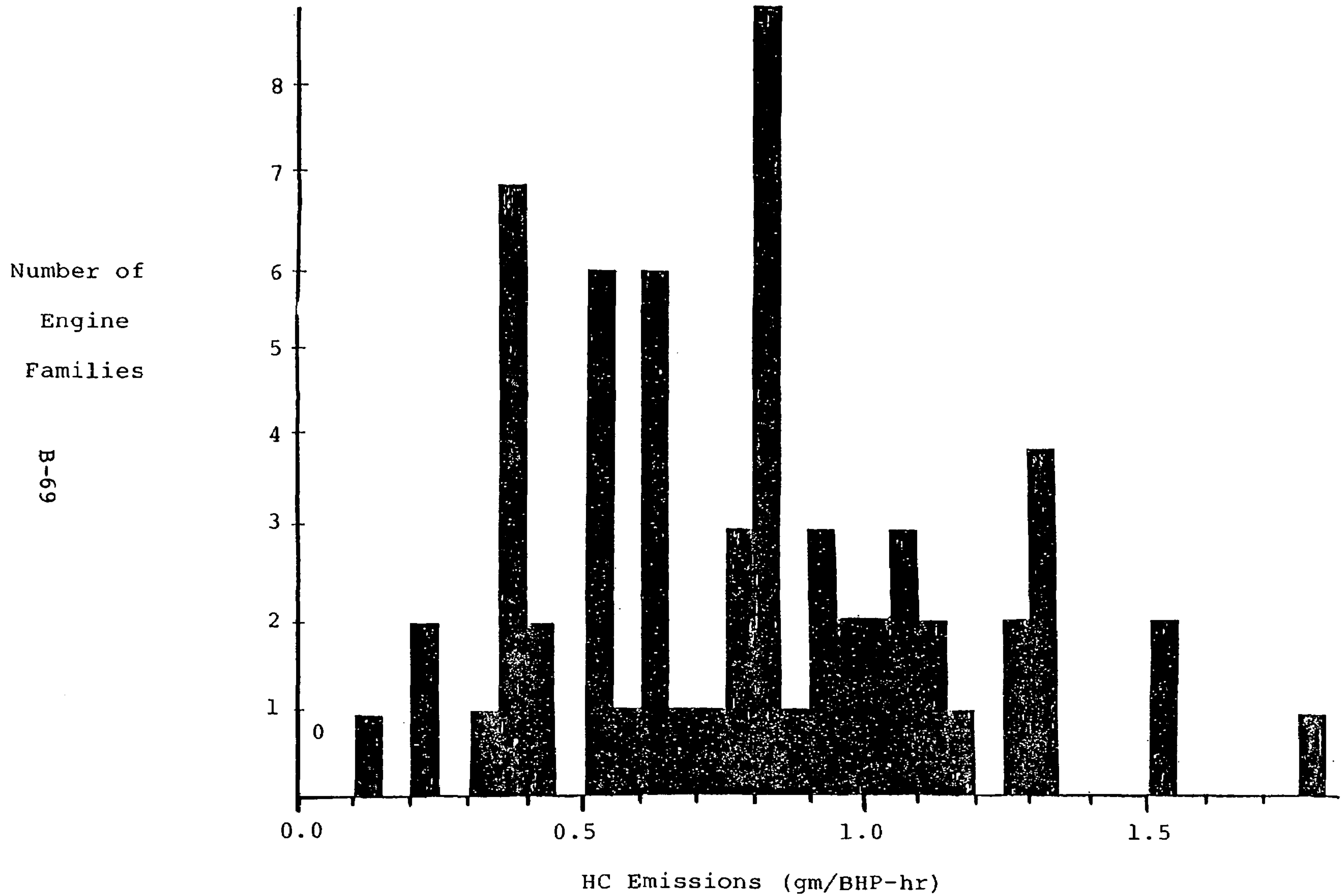


FIGURE 7-4: 1982 Diesel Certification Data (13-Mode BSHC)

g/BHP-hr would be appropriate to provide some flexibility to the industry as they spread out recertification over an additional year. A 0.5 g/BHP-hr standard would likely yield some additional emission reductions, but not to any predictable extent. Practically, however, the relative difficulty in meeting a 0.5 g/BHP-hr standard may in fact force transient certification, which is not consistent with the relief requirements identified. A 0.5 g/BHP-hr steady-state option may actually misdirect technology from transient certification.

As for the provision of a relaxed steady-state option (e.g. to 1.0 g/BHP-hr), we see no justification for such action at this time. The poor correlation between the 13-mode and the transient test gives us little confidence that a 1.0 g/BHP-hr steady-state standard would yield true reductions from the current 13-mode HC standard of 1.5 g/BHP-hr. Since the provision of the steady-state option is intended to allow recertification to be spread over an additional year (i.e., allow carryover of nearly half of the engine families), those engines carried over on the option will receive no additional development work anyway. For these engines, decreasing the steady-state standard from 1.5 to 1.0 g/BHP-hr is irrelevant. As noted above, optional 13-mode standards more stringent than 1.0 g/BHP-hr cannot predict further emission reductions, will likely either force transient certification or misdirect technology towards steady-state certification, and will decrease industry's flexibility in selecting the order in which they recertify.

In summary, a one year deferral in transient testing requirements, (i.e., maintaining the present steady-state HC standard of 1.5 g/BHP-hr, along with the option to certify on the transient test for 1984) is appropriate for relief purposes, and is not practically different in effect from a 1.0 g/BHP-hr standard.

The environmental impact of this deferral is difficult to quantify, since the transient data presented in Figure 7-1 do not represent a complete characterization of all diesel engine families. (In most cases, the manufacturers declined to identify specific engine families when they submitted their comparative data to EPA.) We note, however, that the majority of engines for which data are available already comply with the transient 1.3 standard, and we think it unlikely that their emissions would increase. This will mitigate the overall impact of the 1984 deferral. For those engines which now exceed the transient standard and from which we expect all the environmental gains, a single year deferral is expected to cause an unmeasurable air quality impact.

When advocating a less stringent steady-state option, the industry also argued for an extension of the 13-mode option until recertification (i.e., until the engine family is redesigned, a new family is introduced, or new emission standards apply). With an optional steady-state HC standard of 1.0 g/BHP-hr, this would absolve 73 percent of all engines certified in 1982 from certifying on the transient test. (This does not include those engines which could be certified on the 13-mode in 1983 and 1984, which would then be eligible for carryover). With this option, it is quite likely that few engines - other than new introductions - would be required to be tested on the transient test. This would certainly defer incremental testing and development expenses, but it would also defer for several years most of the emission reductions the transient test was intended to achieve. The analysis in Chapter III indicates that some sort of steady-state option or deferral is required for 1984 to accommodate facility changeover. Beyond that year, however, diesel engine manufacturers will be able to comply with transient testing requirements and do not need further relief.

In summary, to carryover engines on the steady-state test until recertification is required would defer transient testing requirements for the large majority of diesel engines. This would allow continued production for several years of the very engines the transient test was intended to bring into compliance. This is fundamentally different from a single year option or deferral, in which a manufacturer can space out development and certification work over an additional year, but still works to have all engines in compliance by 1985. Since the majority of test facilities have been paid for with investments which are unrecoverable, such a carryover would assure that little environmental returns would be realized from the large facility investment.

III. Conclusions

A. The technical justification for a transient test for heavy-duty diesel engines remains strong. The evidence substantiates EPA's earlier analyses[4] that a transient test is justified in 1984 and even moreso when more stringent NOx and particulate standards apply.

B. A single year deferral in mandatory transient testing requirements would accommodate the facility changeover which the diesel industry indicated was necessary. This deferral represents no practical difference from a relaxed steady-state option, and does not present the difficulties associated with a more stringent steady-state option. A carryover option beyond this (e.g., until recertification was required) would defer most transient testing requirements, and also most of the benefits the transient test was intended to achieve, for no demonstrated reason.

References

1. Derived from Industry Comments Submitted to Public Docket No. A-81-20.

2. "Emissions from Heavy-Duty Engines Using the 1984 Transient Test Procedure, Volume II - Diesel," S. Martin, prepared by the Southwest Research Institute for the US EPA, EPA-460/3-81-031, July 1981.

3. "Status of EPA/EMA Cooperative Test Program," A. Azary, EPA Technical Report, March 1982.

4. Summary and Analysis of Comments to the NPRM: 1983 and Later Model Year Heavy-Duty Engines," Proposed Gaseous Emission Regulations," December 1979.

5. Derived from Industry Comments Submitted to Public Docket No. A-81-11.

CHAPTER 8

SUMMARY AND RECOMMENDATIONS

I. Discussion

A. Implementation Issues

The driving force behind implementation of a transient engine test is its technical justification, i.e., its increased ability over steady-state tests to predict in-use emissions. For gasoline engines, this justification is unquestionably solid.* As discussed in Chapter 7, the justification for diesel engines has become stronger as more data are collected.

Given that a transient test remains technically necessary for heavy-duty engines, we reviewed in Chapter 4 whether the specific test procedure - EPA's cycles and procedures - was technically adequate. The development and procedural details of EPA's test have been the subject of vigorous industry criticism for some time. We reviewed criticism which has arisen since promulgation of the test in January, 1981, and all new emission data acquired since then to address this issue. With respect to the validity of EPA's test cycle, industry's criticisms were speculative. The manufacturers have continually failed to provide real evidence (i.e., factual emission data) that EPA's cycles yield unrepresentative results. In fact, EPA's cycles correlate very well with the alternative cycles proposed by the industry (discussed below), cycles from which the industry removed all objectionable operation. Other available emission evidence also substantiates the adequacy of EPA's cycles. Operationally, claims of repeatability and correlation problems have not been proven. The EPA/EMA Round Robin correlation project yielded reasonably good results, and gave no indication that fundamental problems exist. Such a program has not been run with the gasoline engine manufacturers, although MVMA has asked that one begin. EPA's experience with light-duty vehicle testing indicates that such a program is an important milestone in identifying and correcting problems. That minor problems will exist is almost inevitable; maintaining correlation between emission testing laboratories is an ongoing project for even the most established tests (e.g., LDV test procedure). We anticipate that a number of future technical amendments will be necessary as industry experience with the procedure accumulates. Again, no fundamental problems have been identified and there are no conceptual reasons why ones should exist. In short, EPA's test procedure remains acceptable (although certainly capable of

* See EPA's earlier analysis of this issue in Chapter 1 of the Summary and Analysis of Comments to the NPRM: "1983 and Later Model Year Heavy-Duty Engines - Proposed Emission Regulations," December 1979.

refinements); the large baseline and current technology data bases acquired on the EPA test have not been compromised by any test procedural flaws.

Given a technically necessary and adequate test procedure, we reviewed the economics and leadtime issues associated with the transient test in Chapter 3. All gasoline manufacturers, except Chrysler and International Harvester (gasoline), have made the investment in transient facilities; this investment is not recoverable if the transient test is delayed or withdrawn. The gasoline manufacturers claim that they will not have sufficient leadtime to certify all their engine families on a transient test in 1984; GM will not be able to certify on the 9-mode test in 1984 because of facility changeover. This is not a problem. Due to practical leadtime requirements, the earliest that revised transient emission standards will be implementable is 1985. Since both Ford and GM (gasoline) have spent 100 percent of the required investments in facilities, this effective delay does not provide economic relief. It is advantageous, however, since it allows more leadtime for engine development* and test procedure refinements. For 1984, carryover of 1983 9-mode certification data will be necessary, as will an option to certify on the transient test, to better accommodate the changeover of facilities.

This effective deferral also benefits Chrysler and IHC. After 1984, however, International Harvester currently plans to leave the gasoline engine market and will be unaffected by future test procedural changes. Chrysler's situation remains uncertain. Chrysler has apparently made the business decision that investments in transient facilities will not be made. It is also doubtful whether Chrysler would invest in development work to meet an equivalently stringent steady-state test, were one feasible. (Chrysler has had the option of certifying its relatively lightweight product line on the light-duty truck procedure, but has neglected to do so on account of the procedure's stringency. Chrysler was the only gasoline engine manufacturer to opt for the "quick fix" use of catalytic converter technology in response to the far less stringent 1980 steady-state California emission standards.) Chrysler has also argued that it may not purchase the technology nor contract out the testing, on the grounds that their product may then become cost uncompetitive. There is no fair administrative means by which EPA can exempt only Chrysler from transient requirements. Chrysler's 1982 production will exceed 20,000 engines, so it is difficult to classify it as a small-volume manufacturer for relief purposes. Chrysler's products are not sufficiently different from those of the other gasoline engine manufacturers to provide a basis for any other form of separate classification.

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* Note that EPA will not finalize revised HDE emission standards until the second half of 1982.

The diesel engine manufacturers have also committed a large percentage of their required investments, which are also unrecoverable. All diesel manufacturers will be able to conduct some degree of transient testing in 1984. All facilities will be operational by 1985. This argues for the provision of a steady-state option or deferral for 1984. In Chapter 7, we reviewed all available data comparing transient to 13-mode emissions. For HC, the correlation between test procedures is poor (r^2 = .51); 13-mode HC emissions between 0.5 g/BHP-hr and 1.3 g/BHP-hr cannot predict transient emissions in excess of the transient 1.3 g/BHP-hr standard. For emission control purposes, the 13-mode is inadequate. A deferral in transient testing requirements for a single year is necessary to accomodate the changeover of testing facilities. The industry's recommended level of the optional steady-state standard (1.0 g/BHP-hr) would afford the industry a great deal of flexibility. (Indeed, over 70 percent of all domestic and foreign engine families would be eligible for carryover without recertification.) This option, however, represents no practical difference from a one-year deferral. A more stringent optional steady-state standard would not result in reductions comparable to those achievable using the transient test, and would either misdirect development work needed to achieve true emission reductions or force transient certification anyway.

We have also reviewed in Chapter 7 a less burdensome approach, i.e., allowing indefinite carryover until recertification is required. We concluded that the industry did not need this much relief, based upon our economic and leadtime analysis, and that such a carryover option would sacrifice a large part of the HC reductions attainable on the transient test and already paid for by the facility expenditures. (Such an option effectively defers transient testing requirements for the large majority of diesel engine families.)

In summary, given the single year deferral and the need for relatively little development work to meet applicable standards, the diesel industry will have little problem complying with our recommended transient requirements.

B. Technical Issues

Both the EMA and MVMA submitted alternative transient test cycles (described at length in Chapters 5 and 6). Statistically, these alternate cycles are quite similar to the EPA cycles and the CAPE-21 data base. They are not completely similar, however; identifiable operational differences exist between the cycles and their EPA counterparts. These differences in operation have led to differences in measured emissions. In fact, both alternative test cycles were less stringent than the respective EPA cycle.

On the other hand, emissions from both cycles correlated very well with results from the EPA cycles, and vice versa. (Coefficients of determination (r^2) for all emissions were .90 or greater.) In other words, one cycle should predict emission reductions as well as the other. Given that the industry cycles were developed using different methodologies, the observed correlation tends to confirm all cycles as equally representative, although we note that the number of engines tested to date on the MVMA cycle is small and technical reservations about the MVMA cycle still exist.

To maintain comparable stringency with the alternate test cycles, i.e., achieve the same degree of on-road emission reductions as the EPA cycle, the EPA cycle standards must be corrected. To not do so, i.e., to maintain EPA-based standards with the alternate test cycles, represents a de facto relaxation of standard stringency through test procedure change. This would increase on-road emissions (notably HC) by the percentage of effective relaxation.

The alternate standards for both test cycles were determined by substituting the EPA standards in linear regression equations derived from all available comparative data. Presently there are 30 comparative data points for the RTC and 14 points for the MVMA cycle. More testing may be necessary to more confidently determine the relationship between EPA and MVMA cycle emissions, and to more conclusively establish the viability of the MVMA cycle as a long-term option or replacement.

Equivalent Emission Standards (g/BHP-hr)

	BSHC	BSCO	BSNOx	BSPart
EPA Cycle (gas)	1.3* **	15.5*/35.0**	10.7	NA
EPA Cycle (diesel)	1.3	NA	10.7	.25(P)
MVMA Cycle	0.8* **	12.5*/31.9**	10.9	NA
EMA Cycle	1.1	NA	10.6	.25(P)

NA: No applicable standard.
(P): Proposed particulate standard

* Statutory standards.
** Proposed revised emission standards.

MVMA recommended that EPA adopt its cycle as a complete replacement for the EPA cycle, primarily because of its judgment that EPA's cycle was unrepresentative. EMA requested that its cycle be adopted as an option.

Complete replacement of EPA's cycle at this time is unwise. Such action would be justified if the MVMA cycle were technically superior to the EPA cycle; in our judgment that is not the case. Such action could open to question the accumulated data base which EPA has collected using EPA's cycle, including several baseline studies on which both finalized and proposed emission standards are based. Furthermore, the data base for the MVMA cycle is relatively small, and the calculated EPA/MVMA emission standard offsets may not agree with those derived from a larger data base. (The alternate emission standards are only as accurate as the calculated regression lines.) Furthermore, technical reservations still exist for the MVMA cycle, notably its undocumented derivation and the apparent ease of attaining emission reductions relative to EPA's cycle. (See Chapter 6.) Finally, complete replacement precludes any future flexibility which EPA would retain if the alternate cycles were accepted as options, i.e., the flexibility to analyze and review data collected over several years and during actual certification. Adoption of both alternate cycles as at least short term options, however, addresses all of the industry's technical concerns while leaving EPA the flexibility of selecting a single cycle in the future. Optional use of either procedure at equivalently stringent standards is the wisest course of action.

Finally, as mentioned earlier, a number of technical amendments to the test are being reviewed to cut costs and enhance technical aspects of the test. These will be expeditiously pursued, since they will likely have as great an economic impact as any other test procedural action.

II. Recommendations

1. For gasoline engines, finalize a mandatory transient test for 1985. In 1984, allow both a carryover of 1983 steady-state data and optional certification on the transient test at 1985 standards. This approach gives no special relief or consideration to Chrysler beyond 1984.

2. For diesel engines, finalize the transient test for 1985. For 1984, allow certification on the 13-mode at existing standards to accommodate facility changeover. Also, allow optional certification on the transient test for 1984. After 1984, all engine families would be certified on the transient procedure.

3. Allow the optional use of the EMA and MVMA cycles, certifiable to standards which are equivalently stringent as the EPA cycle-based standards. Based upon experience gathered over time, eventually select a single cycle for gasoline engines and one for diesel engines.

4. As necessary, make refinements and technical amendments to the test procedure itself, with as many changes

as possible being finalized in the upcoming revised 1984 heavy-duty engine emission regulations.

5. Continue cooperation with the industry on joint correlation projects. Pursue standardization of procedures, protocols, and equipment between laboratories as much as is required.

III. Summary of Relief Provided/Anticipated Environmental Impacts

The above recommendations provide the following specific relief to the industry, at the following environmental costs:

1. A one-year deferral in transient testing requirements and applicable emission standards has been provided to the gasoline engine industry. This is due entirely to leadtime requirements and the revised 1984 emission regulations. The extra year will provide greater time for engine development and facility/test procedure improvement; it will also result in another year's production of relatively uncontrolled gasoline engines.

2. A one-year deferral in transient testing requirements will afford the diesel engine manufacturers much flexibility, and will allow them to spread out recertification of their product lines over two model years. Some engine families will continue to exceed the transient HC standard of 1.3 g/BHP-hr for this single year, although the environmental impact will be minimized by the development work which will bring them into compliance by 1985.

3. Specific technical amendments to the test procedure (not addressed here) have the potential to significantly reduce yearly operating costs. Most can be made with no adverse impact on engine emissions. Others (e.g., cold start requirements) will need to be carefully reexamined since environmental impacts are possible.

4. The technical issue of test cycle selection addresses the manufacturers' technical concerns, but is anticipated to have no economic effects either way. If equivalently stringent standards accompany the optional test cycles, no adverse environmental impacts should result from their acceptance.

APPENDICES

APPENDIX 1

REQUEST FOR INDUSTRY COMMENTS ON THE
TRANSIENT TESTING REQUIREMENTS (46 FR 31677, June 17, 1981)

"Study of the 1984 Heavy-Duty Truck Requirements

Regulations for 1984 and later model year heavy-duty engine emissions of HC and CO were promulgated on January 21, 1981 (45 FR 4136). These regulations implemented a broad range of new provisions for heavy-duty engines. One of the key provisions of the regulations was EPA's adoption of a transient engine test procedure to replace the current steady-state test as being more representative of actual truck use.

Since heavy-duty engine manufacturers currently are conducting transient test programs, this study will survey manufacturers' progress to date in developing the transient testing capability needed to meet the 1984 requirements for implementation of the new test procedure. The results of this survey will be used to evaluate whether there is any need to revise those requirements....

...The particular areas in which EPA requests information are as follows:

a. Please identify your needs for transient testing facilities for 1984-85. These needs should be based upon EPA's announced intention to delay implementation of Selective Enforcement Auditing for two years. Include an identification of the number of engine families you plan to certify.

b. Please describe the status of your transient facilities. Identify how many cells you now have and when they became operational plus how many are currently under construction and expected completion dates for those. Describe the equipment complement of your test cells.

c. Please describe any difficulties you are experiencing in developing your testing capabilities. Are you having problems locating vendors to supply necessary equipment? What are delivery times associated with key equipment items? Have economic conditions led you to either delay or cancel purchases of the necessary facilities and equipment? What is your assessment of remaining leadtime for the 1984-85 model years?

d. Please describe the economic impact you are experiencing in developing transient test capability. Itemize the cost of items in your test facilities. Have all outstanding equipment items been purchased, and what would be the impact of a one or two-year delay, in the required implementation date? How are you financing the required investments and what do you consider to be your overall cost of capital? What effect, if any, have the transient test costs had on your future product plans for the heavy-duty market? Please provide a detailed calculation of cost impact on a per-engine basis.

e. Please provide any information you have on transient versus steady-state emissions for regulated pollutants. Have you attempted to establish a relationship on either a family-by-family basis or a product line basis? Please provide any data you have developed.

f. For diesel engine manufacturers, have you done, or are you doing, work to develop transient test capability on eddy-current dynamometers? Please describe your effort and any results.

g. Have you identified any problems with the transient test itself, such as problems with repeatability of test results? Please submit supporting data.

h. Are there specific modifications that could be made to the test to make it more representative of real world conditions and manner of use?"

APPENDIX 2

SOLICITATION OF INDUSTRY COMMENTS AS PART OF THE RULEMAKING FOR REVISED HDE GASEOUS EMISSION STANDARDS (47 FR 1642, JANUARY 13, 1982)

"As mentioned previously, a new HDE test procedure and revised useful life requirements for LDTs and HDEs are both effective beginning in the 1984 model year. As a part of the Administration's regulatory relief program, EPA has committed to a study of the issues pertinent to these provisions and has formally solicited public comment (46 FR 31677, June 17, 1981) (public docket A-81-20). The period to submit information and comment on these issues closed November 1, 1981, for the HDE test procedure and closed December 1, 1981, for the useful life provisions.

EPA recognizes that the transient test and useful life provisions play a key role in the overall emission control program. They directly affect both the manufacturers' compliance strategies and the feasibility of the emission standards. These issues are especially important in this rulemaking and cannot be completely separated from the proposed revised emission standards for HDEs. Given the importance of these provisions in this rulemaking, docket A-81-20 is herein incorporated by reference.

EPA is preserving the option to modify the HDE transient test and useful life provisions as an integral part of the final rulemaking process for this proposed rule. Commenters asserting that changes are needed to make the transient test more accurate or precise are urged to suggest specific amendments where possible. To the extent that issues raised in this rulemaking might elicit additional comment for either the transient test or useful life studies, EPA will accept that comment in conjunction with this rulemaking....

Concerning the transient test, this procedure has been the subject of extensive discussion between EPA and the regulated industry since its promulgation in December of 1979. EPA has visited several transient test facilities and met with manufacturers to discuss their concerns about the transient test procedure. EPA has also received a great deal of correspondence on this topic primarily from the engine manufacturers and their trade associations. EPA remains open to additional substantive comment on the transient test procedure and will fully consider any new information which identifies significant defects in either the method used to develop the transient test or the transient test procedure itself.

EPA has maintained that tighter standards under the steady-state test would provide little assurance that appreciable further emission reductions would be achieved by engines in actual use. Those who assert that the transient test should be deferred should also address whether any significant emission reductions beyond current levels can be attained under the existing steady-state test procedure, and if so, what standards would be appropriate during any period of deferral. If the need for deferral of the 1984 implementation date for the transient test is established during this rulemaking, EPA will consider all comments on the appropriateness of interim standards; EPA will then make a final determination of whether it would be more appropriate to adopt interim standards or to retain the pre-1984 standards with the steady-state test procedure during any period of deferral."

Appendix 3

List of Pertinent References

Report Number	Report/Summary
1	"Truck Driving Pattern and Use Survey, Phase II, Implementation Plan," by Wilbur Smith and Associates, May 7, 1973. This report outlines a sampling and instrumentation plan by which on-road heavy-duty engine operational parameters can be recorded.
2	"Heavy-Duty Vehicle Driving Pattern and Use Survey, Final Report, Part I, New York City," Report No. APT.D-1523, by Wilbur Smith and Associates, May, 1973. This report characterizes usage patterns and population data for heavy-duty trucks in New York City.
3	"Heavy-Duty Driving Pattern and Use Survey: Part II - Los Angeles Basin Final Report," Report No. EPA-460/ 3-75-005, by Wilbur Smith and Associates, February, 1974. This report characterizes usage patterns and population data for heavy-duty trucks in Los Angeles.
4	"Engine Horsepower Modeling for Diesel Engines," EPA Technical Report No. HDV 76-03. by C. France, October, 1976. This report summarizes the methodology used in deriving horsepower models for gasoline engines used in the CAPE-21 study.
6	"Truck Driving Pattern and Use Survey, Phase II, Final Report, Part I," Report No. EPA-460/3-77-009, by Wilbur Smith and Associates, June, 1977. This report summarizes the sampling plan, instrumentation, and data collected in the New York phase of CAPE-21.

Report Number	Report/Summary
7	"Truck Driving Pattern and Use Survey, Phase II, Final Report Part II, Los Angeles," EPA Technical Report NO. HDV 78-03, by L. Higdon, May, 1978. This report summarizes the sampling plan, instrumentation, and the data collected in the Los Angeles phase of CAPE-21.
8	"Analysis of CAPE-21 Horsepower Models," by Systems Control, Inc., July, 1978. In this report to the MVMA, the horsepower models used in CAPE-21 were investigated and checked for their validity.
9	"Heavy-Duty Vehicle Cycle Development," Technical Report No. EPA 460/3-78-008, by Malcolm Smith, July, 1978. This report summarizes the data editing, data manipulation, engine parameter models used, and the overall statistical methodology used in generating heavy-duty engine and chassis dynamometer test cycles.
10	"Category Selection for Transient Heavy-Duty Chassis and Engine Cycles," EPA Technical Report No. HDV-78-01, by C. France, May, 1978. This report summarizes the methodology and statistical comparative procedures used to meaningfully combine truck categories to simplify the CAPE-21 data base.
11	"Analysis of Hot/Cold Cycle Requirements for Heavy-Duty Vehicles," EPA Technical Report No. HDV-78-05, by C. France, July, 1978. This report analyzes the need for separate cold cycles for heavy-duty emission testing; it extrapolates the amount of cold operation present in the CAPE-21 data base.
12	"Selection of Transient Cycles for Heavy-Duty Engines," EPA Technical Report No. HDV-78-04, by C. France, August, 1978. This report summarizes the statistical methodology used in selecting the final test cycles, from the several cycles generated in Report No. 9.

Report Number	Report/Summary
13	"Transient Cycle Arrangement for Heavy-Duty Engine and Chassis Emission Testing," EPA Technical Report No. HDV-78-04, by C. France, August, 1978. This report summarizes the final analysis used in arranging the cycles selected in Report No. 12 for the transient certification test cycles, and also selects the final cold/hot weighting factors.
14	"1969 Heavy-Duty Engine Baseline Program and 1983 Emission Standards Development," EPA Technical Report, by T. Cox, G. Passavant, and L. Ragsdale, May, 1979. This report summarizes the baseline test program from which the transient standards were derived, and summarizes experience and technical discoveries gained in an actual transient test program.
15	Summary and Analysis of Comments to the NPRM: "1983 and Later Model Year Heavy-Duty Engines, Proposed Gaseous Emission Regulations," December, 1979. This document discusses the manufacturers' concerns about the transient test, and places the transient test in its technical and historical perspective.
16	"Heavy-Duty Gasoline Engine Emission Sensitivity to Variations in the 1984 Federal Test Cycle," Cox, T., SAE Paper No. 801370, October, 1980. This report summarizes EPA testing on the variability of transient test emissions associated with dynamometer controller calibration, and gives a detailed description of the transient test procedure with respect to emissions.
17	"Emissions from Trucks by Chassis Version of 1983 Transient Procedure," Dietzman, H., et al., SAE Paper No. 801371, October, 1980. This report summarizes truck emissions generated on a chassis dynamometer when exercised over EPA's transient chassis cycle.

Report Number	Report/Summary
18	"Emissions From Heavy-Duty Engines Using the 1984 Transient Test Procedures," Volumes I and II, Urban, C. and Martin, S., prepared for EPA under Contract No. 68-03-2603, SwRI Report No. EPA-460/3-81, July 1981. This report by EPA's contractor summarizes their transient testing baseline work and experience with the transient test procedure in three separate baseline studies..
19	"The Application of a Three-Way Conversion Catalyst System to a Heavy-Duty Gasoline Engine," Hansel, J., et al., February, 1981. This report summarizes work performed on a prototype heavy duty gasoline engine, in which statutory emissions standards for HC, CO, and NOx were achieved by application of a closed-loop three-way catalyst system, over the EPA transient test.
20	"1972-73 Heavy-Duty Engine Baseline Program and NOx Emission Standard Development," EPA Technical Report No. EPA-AA-SDSB-81-01, Cox T., et al., March, 1981. This report summarizes EPA's in-house transient 1972/73 baseline testing program and the generation of statutory NOx emission standards.
21	"A Review of the Heavy-Duty Gasoline Engine Certification Test Cycles," Final Report to the MVMA, by Arthur D. Little, Inc., Cambridge, April, 1981. In this report to the MVMA, A.D. Little Inc. harshly criticized EPA's test cycles and characterized them as unrepresentative.
22	"Evaluation of the Federal Test Procedure for Heavy-Duty Diesel Engines for 1984 and the Development of the Real Time Test Cycle," by W.L. Brown, Caterpillar Tractor Co., Research Report 88-29, File 18967, June 22, 1981. In this report, Caterpillar's technical personnel review the CAPE-21 data base and, using their own methodology, develop the Real Time Test Cycle for diesel engines.

Report Number	Report/Summary
23	Draft Regulatory Support Document "Revised Gaseous Emission Regulations For 1984 and Later Model Year Light-Duty Trucks and Heavy-Duty Engines," Chapter II, Section B., prepared by OMSAPC, September, 1981.
	This chapter of the regulatory support document gives a detailed description of current technology gasoline engine emission performance over the transient test, and analyzes reductions achievable without oxidation catalysts.
24	"Analysis of Arthur D. Little Inc.'s Report to the MVMA: A Review of the Heavy-Duty Gasoline Engine Certification Test Cycles,'" ECTD Staff Report, January, 1982.
	In this report, ECTD staff analyze A.D. Little's Report to MVMA, and conclude that A.D. Little's analysis was in large part incorrect, unsubstantiated by emission data, and far too strict with respect to achievable accuracies and cycle representativeness.
25	"Status of EPA/EMA Cooperative Test Progam," A. Azary, EPA Technical Report, No., IV-A-1, March, 1982.
	This report summarizes data collected by EPA and the HD diesel engine industry in the first serious attempt to establish correlation between laboratories with the transient test.
26	"Preliminary Report on Statistical Analysis of Heavy-Duty Diesel Engine Emissions Data," N.J. Barsic, prepared for the Engine Manufacturers Association/Technology and Methods Subcommittee.
	The report analyzes emission data collected in the EPA/EMA Round Robin correlation project, using several statistical techniques.

APPENDIX 4

ECTD's Analysis of A.D. Little's Report to the MVMA

ECTD Staff Report:

Analysis of Arthur D. Little Inc's Report to the MVMA: "A Review of the Heavy-Duty Gasoline Engine Certification Test Cycles"

January 1932

Table of Contents

I. Introduction

On January 21, 1980, EPA promulgated Final Rules for the control of gaseous emissions from 1984 and later model year heavy-duty gasoline engines. A major component of these rules was the adoption of a new transient emission test procedure. The intent was to model over-the-road operation of an "average" truck as closely as a single laboratory test procedure could, thereby allowing over-the-road exhaust emissions to be predicted with much greater confidence than the older steady-state tests.

In April, 1981, Arthur D. Little, Inc. of Cambridge, Massachusetts published a report entitled "A Review of the Heavy-Duty Gasoline Engine Certification Test Cycles," commissioned and funded by the Motor Vehicle Manufacturers Association (MVMA) of the United States, Inc. A.D. Little, Inc. concluded that the EPA test cycles (both chassis and engine) were unrepresentative of the on-road data base, and was harshly critical of EPA's methodology and conclusions.

In this report, the ECTD staff analyzes the A.D. Little report and the validity of its conclusions. Section II of this report presents an overview of the heavy-duty engine environment, and EPA's cycle generation methodology. Section III summarizes ECTD's point-by-point analysis of the A.D. Little report. This point-by-point analysis is attached as an Appendix.

II. Overview

A. Heavy-Duty Engine Test Procedures: Design Intent, Predictive Utility, and Inherent Compromise

Heavy-duty gasoline engines are subjected to a wide range of operating conditions in the field. They operate in many different traffic patterns, over many different terrains, carrying a wide variety of loads and in a wide variety of vehicles with varying numbers of axles, many different commercial applications, and different numbers of transmission gears. To meet the market's wide variety of needs, many different engine types and characteristics are manufactured. The major challenge in test cycle development is to compress this diversity into a workable laboratory test procedure.

Intuitively, on-road emissions from an "average" heavy-duty engine are best predicted by a test procedure which contains all operational parameters in their average on-road proportion and severity. This point is made with the recognition that there is probably no such thing as an "average" truck or truck-trip, given the wide range of engine operation in the field. Any single test cycle designed to model the real world will be only one of a virtually infinite number of possible cycles. This reality is nothing new. It was stressed by the MVMA in their original comments to the proposal containing the new test cycle:

> "...Considering the diversity of design and use of heavy-duty gasoline powered vehicles, it is probable that no "representative" driving cycle exists...."[1]

In short, a single test cycle for heavy-duty engines must be an approximation at best. This is fundamentally identical to the circumstances surrounding the light-duty vehicle FTP, or the current heavy-duty engine steady state FTPs. Each is a short laboratory test attempting to model highly diverse environments and operational conditions.

An alternative to a single engine cycle would be a multitude of test cycles, each being representative of a specific application. This alternative would lead to very complicated certification procedures, and the engine manufacturers would most likely attempt to certify one engine configuration for as many different test cycles as possible. The improved representativeness of multiple engine cycles does not justify the added burden for both EPA and the engine manufacturers.

Another alternative is to use a chassis (vehicle) test cycle. However, since many engine manufacturers do not manufacture trucks, they obviously prefer an engine test procedure. Also, the diversity of truck types and the large number of driveline options for each truck type, would necessitate certification procedures of such a complicated nature that this alternative would be unworkable. The heavy-duty engine industry has in fact argued against this approach for these reasons.

Steady-state emission tests have historically been recognized as simple procedures in concept and in operation. Their predictive utility, however, is poor primarily because gasoline engines are easily optimized to perform well on the limited number of test modes. Secondly, they ignore significant emissions-producing operational modes of gasoline engines such as transient operation and cold starting. Emissions reductions achieved in the laboratory, as measured by steady-state tests, are not achieved in actual on-road operation. This was noted early in the certification process for light-duty vehicles when the original 7-mode steady-state procedure was replaced by the transient CVS-72 procedure in

1972. As technology was applied to meet stricter emission standards, i.e., engine emission control systems were designed and optimized for best performance on a specific test procedure, steady-state test results digressed further and further from real-world emissions. Similarly, many studies and actual testing data revealed the same shortcomings in the heavy-duty gasoline engine 9-mode procedure.[1] In short, the 9-mode represents an unreasonable approximation of the real world. For this reason, in 1972 EPA began work on a new, more representative test procedure.

B. EPA's Heavy-Duty Test Cycle Development Methodology

It was recognized that any revised heavy-duty engine test procedure would need to be based on actual on-road truck operational data. In October 1974, in cooperation with the industry-staffed Coordinating Research Council-Air Pollution Research Advisory Committee (CRC-APRAC), EPA began the largest on-road truck study to date (the CAPE-21 project) in New York City, and shortly thereafter, in Los Angeles. Actual commercial trucks were instrumented and driven through their normal daily rounds by their own drivers, while engine and vehicle operational parameters (speed, power, temperature, etc.) were recorded. These recordings of the daily operation of the 110 trucks formed the data base from which the representative test cycles were to be generated.

This data base was input into a computer and used to generate thousands of candidate driving cycles. This cycle generation was accomplished by the computer simulating an engine driving down a probabilistic road: the transition from the present speed/power mode to the next speed/power mode in the resulting cycle was determined by the observed frequency of occurrence of the same transition in the CAPE-21 data base. Those transitions most frequently observed in the field were those which occur most frequently in the test cycles. The generated cycles were then screened using statistical tests and engineering judgment; those closest to the CAPE-21 data base were selected as the final cycles.

Separate cycles were generated for each subset of the data base determined to be sufficiently different to warrant its own cycle. Practical limits to the number of subsets exist: each division of the data base reduces the amount of data available for subset cycle generation, whi1^ also lengthening the eventual emission test. Possible subsets included geographic factors, (New York vs. Los Angeles), road type (freeway vs. non-freeway), engine temperature (cold vs. warm vs. hot engine), engine type (gasoline vs. diesel), vehicle type (2-axle vehicle vs. 3-axle vehicle,) etc. EPA concluded that only Los Angeles vs. New York, freeway vs. non-freeway, and gasoline vs. diesel were significantly different enough to warrant separate cycles, thereby creating 4 gasoline and 4 diesel engine cycles. (Four chassis dynamometer cycles were also generated, but these have yet to be used in any rulemaking concerning exhaust emissions.) The subsets chosen represented EPA's judgment of the best available compromise.

These cycles (hereafter referred to as subcycles) were then arranged end-to-end into a single cycle, and baseline emission testing per the requirements of the 1977 Amendments to the Clean Air Act (CAA) of 1970 was begun. Baseline emission levels and emission standards were generated based upon the transient test. The actual test procedure consists of the cycle being run twice--first after the engine has reached equilibrium at ambient air temperature (the "cold" start), followed by a 20-minute pause (hot soak), then a rerun of the cycle (hot start). Emissions from both cycles are then weighted (1/7 from the cold and 6/7 from the hot) into a composite test result.*

Throughout the cycle and standard development process, EPA documented and published the results and methodologies used. These publications are listed as References 2-15, and form the technical basis for the cycles.

Throughout the cycle development process, the end product was always envisioned to be a workable and representative test procedure. In the development of any test procedure, however, there is an inherent tradeoff between procedure simplicity and procedure representativeness. Arguments were made by A.D. Little, Inc. that the compromises taken and the underlying methodologies used in EPA's cycle development program were in many cases inappropriate.

III. Summary: ECTD's Analysis of A.D. Little, Inc.'s Report to the MVMA

General Conclusions

1. A.D. Little's criticisms of EPA's cycle development methodology are based upon statistics and conjecture. No emission data are presented or referenced to substantiate any claims of engine or chassis cycle unrepresentativeness.

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* This is identical in methodology to the light-duty Federal Test Procedure (FTP), with the exception of the numerical value of the cold/hot weighting factors. The light-duty weighting factors are .43 for the cold cycle and .57 for the hot.

2. The majority of A.D. Little's analysis of test cycle validation is incorrect, being based upon incorrectly applied statistical tests and incorrectly chosen comparative parameters.

3. A.D. Little's statistical analysis holds EPA to unreasonable and impractical standards of accuracy. A notable example is its analysis of truck sample size in which it argues that in some cases over a thousand trucks are necessary to accurately predict the percentage of operation in some subcycles. A.D. Little's harsh criticism of the weakness in EPA's methodology neglects to mention that the weakness was not imposed by EPA error, but rather by fundamental limitations which the input data placed upon the applicable statistical techniques, and by the compromises required to compress the vast data base into a workable laboratory test procedure.

4. A.D. Little's arguments were not only narrow in focus (neglecting practicalities and ignoring emissions), they were entirely negative. No single alternative to EPA's methodology was advanced. No evidence was presented that EPA neglected a more representative approach in lieu of the methodology chosen. No specific suggestions were made about how the cycles could be improved.

5. EPA sees nothing in the A.D. Little report to warrant changing the conclusion that the engine cycles are representative of the data base. The implications from all emission data collected to date on the engine cycles are that emissions are not exaggerated by the Monte Carlo technique. Changes to the engine cycles to improve the agreement of their operational parameter summary percentages with those of the CAPE-21 data cause negligible or minor (less than 5 percent) changes in measured emissions. This is true even for the most operationally sensitive modes and emissions evaluated.

6. EPA has collected no emission data on the current chassis cycle, the criticism of which comprised the majority of A.D. Little's report. The chassis cycle has not been, nor is it intended to be, used in any exhaust emissions certification test procedures. A.D. Little's statistical arguments of chassis cycle unrepresentativeness are generally unconvincing; however, they are correct in pointing out that the percentage cruise operation in the overall chassis cycle is somewhat less than that indicated by CAPE-21. Whether this represents a measurable difference in emissions is unknown.

7. A.D. Little's statements concerning combustion engine emissions are based upon a brief literature review, and not upon actual "hands-on" experience with emission testing or emissions control. A.D. Little, therefore, attributes many

engine parameters (e.g., second-by-second thermal history, cylinder wall temperature, etc.) with larger than life emission significance, *whereas only a few (e.g., vehicle inertia weight,* air/fuel ratio, frequency and degree of transient and full power fuel enrichment, cold-start effects) will in actuality dominate the results of a laboratory emissions test. As substantiated by EPA's engine cycle emission data, A.D. Little overestimates the emissions sensitivity of the test cycles to the cycle generation methodology. *Note that it was a highly* conjectural overestimation, being based upon absolutely no emission data whatsoever.

8. Finally, EPA has always maintained that the cycles and test procedures are not perfect and are subject to modifications, if actual emission testing experience indicates that modifications are warranted. A.D. Little and the heavy-duty gasoline engine industry it represents have failed to present such evidence, and failed to present any specific alternative to the specific parts of the cycles or procedures with which they disagree.

References

1. Summary and Analysis of Comments to the NPRM: "1983 and Later Model Year Heavy-Duty Engines, Proposed Gaseous Emission Regulations," U.S. EPA, OANR, OMS, ECTD, SDSB, December 1979.

2. "Truck Driving Pattern and Use Survey, Phase II, Implementation Plan," William Smith and Associates, May 7, 1973.

3. "Heavy-Duty Vehicle Driving Pattern and Use Survey, Final Report, Part I, New York City," Report No. APT. D-1523, William Smith and Associates, May 1973.

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5. "Engine Horsepower Modeling for Diesel Engines," U.S. EPA, OANR, OMS, ECTD, SDSB, France, C., Report No. HDV 76-03, October 1976.

6. "Engine Horsepower Modeling for Gasoline Engines," U.S. EPA, OANR, OMS, ECTD, SDSB, Higdon, L., Report No. HDV 76-04, December 1976.

7. "Truck Driving Pattern and Use Survey, Phase II, Final Report, Part I," Report No. EPA-460/3-77-009, William Smith and Associates, June 1977.

8. "Truck Driving Pattern and Use Survey, Phase II, Final Report Part II, Los Angeles," U.S. EPA, OANR, OMS, ECTD, SDSB, Higdon, L., Report No. HDV 78-03, May 1978.

9. "Analysis of CAPE-21 Horsepower Models," Systems Control, Inc., July 1978.

10. "Heavy-Duty Vehicle Cycle Development," U.S. EPA, OANR, OMS, ECTD, SDSB, Smith, Malcolm, Report No. EPA 460/3-78-008, July 1978.

11. "Category Selection for Transient Heavy-Duty Chassis and Engine Cycles," U.S. EPA, OANR, OMS, ECTD, SDSB, France, C., Report No. HDV 78-01, May 1978.

12. "Analysis of Hot/Cold Cycle Requirements for Heavy-Duty Vehicles," U.S. EPA, OANR, OMS, ECTD, SDSB, France, C., Report No. HDV 78-05, July 1978.

References (cont'd)

13. "Selection of Transient Cycles for Heavy-Duty Engines," U.S. EPA, OANR, OMS, ECTD, SDSB, Wysor, T., and France, C., Report No. HDV 77-01, November 1977.

14. "Transient Cycle Arrangement for Heavy-Duty Engine and Chassis Emission Testing," U.S. EPA, OANR, OMS, ECTD, SDSB, France, C., Report No. HDV 78-04, August 1978.

15. "1969 Heavy-Duty Engine Baseline Program and 1983 Emission Standard Development," U.S. EPA, OANR, OMS, ECTD, SDSB, Cox, T., Passavant, G., and Ragsdale, L., Report No. EPA-AA-SDSB-79-23, May 1979.

16. "1972-73 Heavy-Duty Engine Baseline Program and NOx Emission Standard Development," U.S. EPA, OANR, OMS, ECTD, SDSB, Cox, T., et al., Report No. EPA-AA-SDSB-81-01, March 1981.

17. "Heavy-Duty Gasoline Engine Emission Sensitivity to Variations on the 1984 Federal Test Cycle," Cox, T., SAE Paper No. 801370, October 1980.

18. "The Application of a Three-Way Conversion Catalyst System to a Heavy-Duty Gasoline Engine," Hansel, J., et al., SAE Paper No. 810085, February 1981.

19. Draft Regulatory Support Document "Revised Gaseous Emission Regulations For 1984 and Later Model Year Light-Duty Trucks and Heavy-Duty Engines," Chapter II, Section B, Prepared by OMS, September 1981.

20. "Emissions From Heavy-Duty Engines Using the 1984 Transient Test Procedures," Volumes I and II, Urban, C. and Martin, S., Prepared for EPA under Contract No. 68-03-2603, SWRI Report No. EPA-460/3-81.

21. "Emissions from Trucks by Chassis Version of 1983 Transient Procedure," Dietzman, H., et al., SAE Paper No. 801371, October 1980.

22. <u>Introduction to Applied Statistics</u>, A Course Outline of Statistics 402, Rothman, E.D., University of Michigan, July 1979.

23. "A Review of the Heavy-Duty Gasoline Engine Certification Test Cycles," Final Report to the MVMA, by Arthur D. Little, Inc., Cambridge, April 1981.

24. <u>Introduction to Statistical Analysis</u>, Third Edition, Dixon, Wilfred J., Massey, Frank J., Jr., 1969.

Appendix

Note: The issues and subject matter presented and discussed in this Appendix are listed and numbered as they appeared in the A.D. Little report to permit easy referencing. A summary of the A.D. Little analysis for each point is presented and followed by EPA's analysis. Suffixes have been added to the A.D. Little numbering system to differentiate between A.D. Little and EPA analyses. The suffixes "L" and "E" will be used for A.D. Little and EPA analyses, respectively.

1.0 Introduction

2.0 Summary and Conclusions

3.0 Engine Operational Parameters

3.1 L -- All engine operational parameters must be carried through on the test cycle and simulated by a reasonable duplication to truly represent over-the-road operation.

3.3 L -- Engine speed, load, speed/load relationships, speed/load history, and engine thermal history must be manipulated in the laboratory in a manner which will duplicate the over-the-road state of the engine, although it is recognized that some compromises must be made in the test cycle in order to make it a feasible, cost-effective procedure.

3.4 L -- During transient operation, critical engine variables may be at off-design or non-optimum operating points for much of the time. It is not necessary to follow an exact over-the-road speed or load schedule so long as load excursions are representative (i.e., do not exceed the magnitude or rate of those experienced on-road), and are present for a representative portion of total operating time.

3.6 L -- Speed/load relationships (including dwell times at constant load) must be maintained. An unrealistic operating condition is a change in engine speed without a change in engine torque.

3.7 L -- Engine thermal history is important relative to emissions. A representative test must include cold operation (including operational differences of a cold engine), unless cold emissions represent an insignificant portion of the total.

3.8 L -- Since thermal conditions are influenced by previous speeds and loads, it is important that engine speed/load history be simulated with some accuracy, although this requires knowledge (and/or assumptions) of individual vehicle, driver, road, and trip characteristics. It should to possible, however, to define representative characteristics of speed/load history for inclusion in a test cycle.

3.9 L -- Chassis dynamometer cycles are subject to the same criteria with respect to vehicle speed, and engine thermal history.

3.1-3.9 E -- A.D. Little conducted what was essentially a literature review on the subject of combustion engine emissions. For the most part, A.D. Little's limited summary of pertinent literature correctly identifies sources of tailpipe emissions, but at no time does A.D. Little discriminate between major, minor, and insignificant sources. A.D. Little's Chapter 3.0, "Engine Operational Parameters" is an academic review containing neither actual emission data to support the authors' contentions, nor any evidence that A.D. Little has any "hands-on" or other experience with emissions testing, measurement, and control.

Since February of 1978, EPA's Ann Arbor facility has performed nearly 1,000 transient emission tests on heavy-duty gasoline engines and over 300 on heavy-duty diesels. This testing encompasses engines and technologies which include uncontrolled, current technology, and advanced technology prototypes. Other tests explored emissions sensitivity to variations in engine, cycle, and test procedure parameters. EPA has acquired a substantial data base and substantial "hands-on" experience with both the transient test procedure and the data generated therefrom.[15,16,17,18,19] The Southwest Research Institute's Department of Emissions Research, under contract to EPA, has also been running transient emission tests since June of 1978 on both HD gasoline and diesel engines. (See References 20 and 21.) The above experience, plus 10 years of light-duty emissions testing experience, gives EPA confidence in its ability to identify important emission parameters.

A.D. Little has identified and selectively addressed those emission parameters they believe most associated with EPA's cycle development methodology, inferring that "errors" in cycle development affect the emissions measured over the resultant cycle. We shall defer most of our discussion until later in the Appendix where the particulars of cycle development methodology are more thoroughly discussed; however, several points need to be made.

First of all, A.D. Little presents no emission data to support its conclusions. EPA has always maintained that if a cycle is representative of over-the-road operation, the exhaust emissions measured over that cycle will also be representative. This by no means implies that every on-road characteristic is critical with respect to emissions. This is also true with respect to the proportional time any on-road characteristic is present in the cycle. The A.D. Little report makes several claims of EPA cycle non-representativeness on the basis of idle times being too short, high-power cruises being too short, and other operational distribution differences between the individual subcycles and the CAPE-21 data. A.D. Little then makes sweeping conclusions of unrepresentativeness, yet makes no inferences and presents no data on the emissions impact of these discrepancies. The cycle is, after all, used in an emissions test procedure, and the only reasonable basis for concluding non-representative emissions generation is to demonstrate significant changes in emissions arising from the discrepancies in operational parameters. Unsupported and unquantified inferences arising from a casual review of combustion emission literature is insufficient proof.

Secondly, the majority of A.D. Little's criticisms throughout their report focuses on the chassis cycles, as opposed to the engine cycles. This is surprising, considering that all heavy-duty engine exhaust emission test procedures and exhaust emission standards are based upon the engine dynamometer cycles. We shall, nonetheless, address the criticisms since the cycle generation methodologies were similar.

Furthermore, A.D. Little has identified several sources of emissions and related these to the effects of specific engine operation, i.e., how the engine operation in a test procedure can affect measured emissions. At no time, however, are the relative magnitudes of each emission source discussed. A satisfactory test procedure can exclude all minor and insignificant sources, so long as it includes all dominant sources. The most significant determinant of engine exhaust emissions is air/fuel ratio, both overall and locally within the cylinders. Air/fuel ratio changes continually in over-the-road operation, both as a function of load and from increases in load (transient enrichment from the accelerator pump), full power operation (power valve enrichment), motoring, and from temperature effects. The degree of enrichment and nominal air/fuel ratio calibration are determined by the engine designer in response to on-road power and driveability needs. These three major sources of emissions: transient loads, full power operation, and cold starting, must be properly represented in the test procedure if predictable on-road control is to be achieved. For the chassis cycle, the vehicle inertia weight and road load horsepower calibration of the dynamometer (which are independent of the cycle used) are also major determinants of overall measured emissions.

Finally, identification of the real issues in this test procedure controversy is warranted. The emission standards generated by the Clean Air Act Amendment methodology were derived on the full transient test procedure. If a systematic bias in emissions from the "real-world average level" were to exist,* that bias has been carried through to the emission standards. If the test procedure generates higher emissions the standards will be comparably higher. Emission penalization of a manufacturer as a result of the certification test procedure is not the issue. Representativeness itself is not the all-important issue the heavy-duty gasoline industry claims. The industry was perfectly content to certify engines on the considerably less representative 9-mode for the last eleven years. This is not said to deemphasize representativeness--great pains were taken during cycle development to assure maximum representativeness in a practical procedure, and most of this analysis addresses that issue. This is to say, however, that the industry is not so much interested in achieving a perfect cycle, but rather they are most concerned with ease of compliance (in terms of cost and technical effort) and possible impact of resulting control strategies on engine performance and durability. For our part, the ECTD staff considers a test procedure to be a tool to direct emission control technology towards achieving in-use emissions reductions. To do so, it must adequately represent in-use operation. The true test procedure controversy arises when those modes which EPA considers most significant with respect to emissions are also those which the industry considers most problematic to control.

The transient test procedure as promulgated by EPA is by no means unalterable. The regulatory support documents from the Final Rulemaking openly stated that "...there should be no problem in modifying procedures, changing validation and dynamometer specifications, and making any changes deemed sound if actual testing experience suggests that additional changes to the test procedure are warranted."[1] The laboratory test procedure was developed primarily at EPA's Ann Arbor facility, using equipment and procedures which were technically sufficient, but not necessarily the state-of-the-art or most cost effective. Given the diversity of product lines,

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* This is by no means conceded. All data to date implies that such an offset is unlikely, or quite small (see the remainder of the Appendix).

laboratory equipment alternatives, and technical experience and opinion within the industry, there comes a point when unilateral development of an emission test procedure must stop and a consensus with the industry reached. Attaining a technical consensus requires constructive technical feedback, including emission data, from the industry. This has not occurred. To date, all feedback from the heavy-duty gasoline industry, as typified by the A.D. Little report, has been negative, characterizing the transient test procedure as in toto unrepresentative and technically deficient. EPA has been presented an all or nothing proposition. The gasoline engine industry, however, has not presented any emission data to substantiate claims of unrepresentativeness, nor have they suggested specific improvements or alternatives to the present transient procedure, or even identified acceptable alternative methods of test procedure development. The weight of present technical evidence indicates that the transient test cycles and procedure are by and large sufficiently representative of in-use trucks. This by no means indicates that the cycles or procedure are perfect, and are not capable of further improvement.

4.0 Assumptions and Methodology Used in the Development of Test Cycles

4.2 L -- The Markov model, a second-by-second technique which assumes that the likelihood of going to the next speed and load depends only upon the present speed and load, neglects speed/load history of more than one second. This approach did not capture the smooth cruise, acceleration, and deceleration operation found over-the-road. In short, erratic cycles with unrepresentative speed/load patterns were generated. The transitions in speed and load were random; holding times at given speeds and loads were "memoryless" (i.e., were independent of operation more than one second in the past), and long-term cruising (i.e., steady-state operation) were not included.

4.2 E -- Several of A.D. Little's observations about the Markov (Monte Carlo) model are correct. Characteristic speed/load shift patterns do not appear in the cycles. Holding times and transitions were independent of operation more than one second in the past. Extended steady-state operation was not included in the cycle. These facts are more easily understood when one realizes that the Markov model makes no assumptions about the data base; transitions from one speed/load state in the cycle to the next occurs with the same probability as the identical transition observed in the aggregate data base, i.e., all trucks and all truck trips combined. Implicit in the inclusion of a given speed/load shift pattern into a cycle are several assumptions, e.g., road, trip, traffic, and driver characteristics, number and speed ratios of transmission gears, accelerating or decelerating operation, etc. Given the large number of trucks and truck trips and the extreme variety of engine operations accumulated on-the-road, the better statistical model is that which held the fewest preconceived notions and made the fewest assumptions about the data.

As mentioned earlier, the prime determinants of representativeness are emissions measured over the cycle. A.D. Little's analysis of thermal history implied that uncharacteristic speed/load shift patterns generated unrepresentative emissions. Several manufacturers have argued that "erratic" and continually changing cycles, the "nervous foot" syndrome, contribute to excessive transient enrichment and, therefore, high HC and CO emissions on gasoline engines. It has also been argued that unrealistic speed/load transitions (e.g., a change in speed without a change in load) have been incorporated into the cycle, thereby creating unrealistic emissions. To date, no emission data have been advanced to support these claims.

In reviewing the A. D. Little report, one of our major criticisms is that it fails to differentiate between major and minor emission sources. A case in point is its discussion of engine thermal history. It is an established fact that cold engine HC emissions are substantially higher than those of a warm engine. The major reason for this is the effect of a cold inlet manifold on the ability of gasoline to vaporize uniformly in the inlet air. Cold manifold walls cause condensation of a large portion of the gasoline. Cold enrichment by the choke mechanism attempts to alleviate driveability problems, but consequently results in excessive unburned fuel emissions. As the intake manifold warms up, the problem gradually disappears. A.D. Little has argued, however, that the Monte Carlo technique is unrepresentative because it neglects engine thermal history of more than one second, claiming unrepresentative emissions because of the unrepresentative second-by-second changes in cylinder wall temperature. But how large are these potential emission differences? Are they measurable, and if so, significant? A.D. Little cites "experience"* to indicate that several seconds are required for emissions at any given state to stabilize, yet fails to mention that such time delays are primarily results of mixing and gas residence characteristics of the exhaust stream reacting to the change in operation, and of the finite response limitations of the downstream emissions analyzer. Given the fact that there are almost 17 combustion events per second per cylinder in an

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* A personal conversation with a single industry engineer.

engine running at 2,000 rpm, one could argue that cylinder wall temperature is much more responsive to second-by-second operational changes than the downstream emissions analyzer. In short, the effect of the Monte Carlo technique on engine temperature-dependent emissions is most likely unmeasurable. Intake manifold temperature, the major source of cold emissions, increases slowly (over a period of several minutes) from a cold start and is certainly unaffected by the Monte Carlo technique.

This judgment, plus the observation that the Monte Carlo "nervous-foot" characteristic does not significantly bias emissions measured over the transient cycle, is implied from emission data generated at EPA's Ann Arbor laboratory.

First of all, Table A-1 presents comparative 9-mode and transient emission data on fifteen 1969 model year heavy-duty gasoline engines. These engines were uncontrolled with respect to emissions. Although absolute correlation between the two test procedures is unlikely, primarily because each procedure exercises different emissions-producing mechanisms within the engine, the average levels of emissions for both procedures are highly illustrative. If a systematic, gross overstatement of HC and CO emissions arising from throttle activity (or any other parameter) were present, it should show up as a large difference between uncontrolled transient and 9-mode emissions. In fact, transient HC emissions are less than 9-mode, despite the fact that both cold-start and transient-throttle operation are included in the transient test. (Closed throttle motoring is somewhat less controlled.) Transient CO is 24.7 percent higher, but we note that the 9-mode test does not include full-power operation, while the transient does, and full-power Los Angeles Freeway (LAF) operation accounts for 68.9 percent (from Table A-8 where the contribution of the cold-start LAF is 12.6 percent added to the hot-start LAF contribution of 56.3 percent) of CO measured over the transient cycle on the highest emitting current technology engines. In short, although the two test procedures are not identically comparable, one would expect gross emission differences to exist if the "nervous foot," or any other aspect of the transient test, were grossly inappropriate.

Secondly, Reference 17 presented data detailing the effect of dynamic throttle activity on transient emission results. Throttle activity was first varied and the overall effect on emissions measured. The data show that past a certain threshhold of throttle activity, HC and CO emissions increase dramatically, as would be expected when transient enrichment becomes excessive. Below that threshold, emissions are essentially constant, even as throttle activity is decreased

Table A-I

Uncontrolled Emission Levels from Fifteen 1969
Model Year HD Gasoline Engines (in grams per horsepower-hour)

	HC		CO		NOx	
Engine	Transient	9-Mode	Transient	9-Mode	Transient	9-Mode
IHC 304	11.22	17.0	127.8	119.9	6.70	6.04
Chrysler 318	7.96	8.31	87.0	50.5	7.60	9.75
IHC 345	7.12	7.84	76.5	47.0	6.46	9.33
GM 350	6.21	7.25	126.1	131.5	5.36	4.21
Ford 300	7.81	9.79	233.4	235.8	4.91	4.35
IHC 345	6.41	8.99	94.0	89.0	5.59	6.19
GM 366	8.59	9.25	187.9	122.3	5.32	5.85
Ford 361	14.12	10.19	228.4	180.0	5.43	4.83
Ford 360	7.96	11.29	132.2	97.4	6.63	6.17
GM 292	8.54	8.52	172.8	95.1	5.14	7.16
Chrysler 318	8.82	9.74	144.3	112.3	7.54	8.25
Ford 361	9.57	10.03	197.6	160.2	5.09	6.17
Ford 360	5.92	6.49	75.3	43.2	6.88	6.35
GM 350	8.64	9.81	150.4	148.2	4.58	3.96
Chrysler 361	12.63	10.27	168.7	133.5	6.01	5.94
Mean:	8.77	9.65	146.8	117.7	5.95	6.30
STD Dev:	2.32	2.39	51.4	52.0	.96	1.73
% Difference, Transient from 9-Mode:	-9.1%		+24.7%		-5.6%	

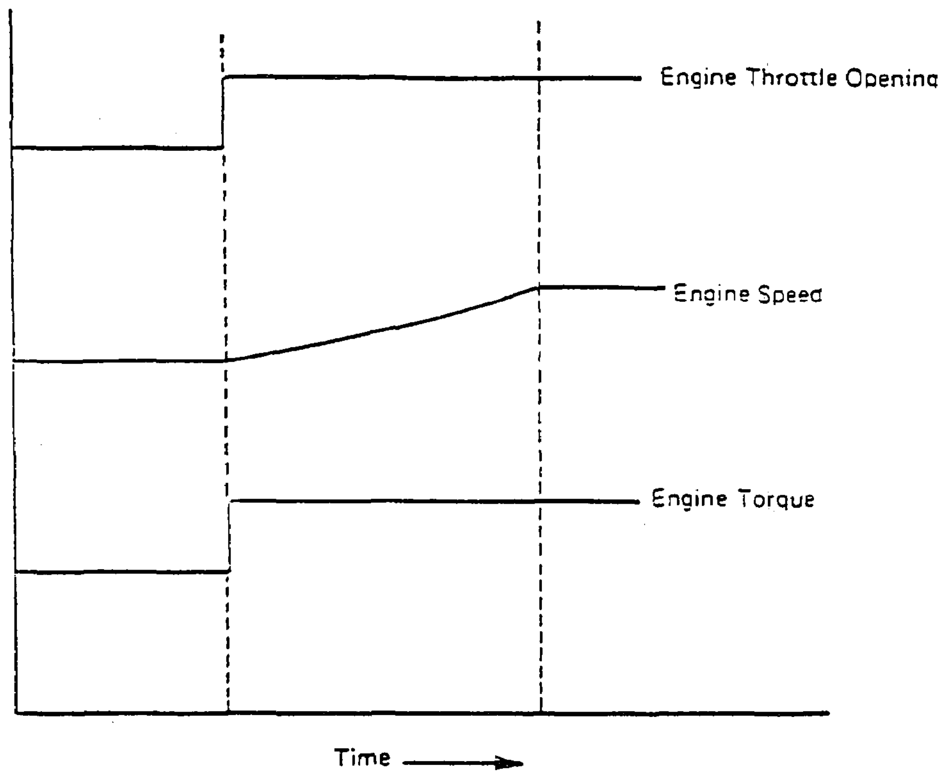
well below that activity normally used in the transient procedure, i.e., the cycle was mechanically smoothened. If the test procedure were inherently overactive, one would expect emissions to continue decreasing as throttle activity was further dampened.

In summary, the Monte Carlo technique did not produce characteristic speed/load shift patterns. However, the cycle that was produced generates emissions which are representative, as implied by the data above, and was produced without major assumptions about the data, and hence is a statistically better model. Again, this is argued with a complete lack of emissions evidence to the contrary.

Finally, both A.D. Little and the industry have argued that unrealistic modes of engine operation were included in the cycle by the Monte Carlo technique. Many of these comments have already been addressed in Reference 1, but A.D. Little argued that an increase in engine speed without a change in load is unrealistic. A.D. Little presented an illustration, reproduced here as Figure A-1, depicting its version of realistic engine acceleration. A.D. Little argued that changes in engine speed without changes in engine torque were unrepresentative. We dispute this unsubstantiated generalization. Note that engine speed can remain constant while torque increases as a truck begins to climb a hill and more throttle is applied to maintain vehicle speed. Note also in Figure A-1 that at any time after the intitial change in torque, the engine speed increases while the engine torque is constant. (That component of engine torque affecting acceleration gradually decreases to zero, while that arising from increased vehicle aerodynamic drag and rolling friction increases by the same amount.) Engine accelerations during motoring are also realistic, when one considers that truck drivers frequently downshift while braking with the engine. What is not maintained in the test cycle, as discussed above, are the familiar patterns of gear shifting during accelerations and decelerations. All second-by-second operation in the cycles, however, are physically explainable. A.D. Little's hypothesized generalizations of possible truck operation do not reflect what was actually recorded in the CAPE-21 project.

4.3 L -- EPA's methodology of forcing accelerations at the beginning and decelerations at the end of each 5-minute cycle, was mandated by deficiencies in the Ma...v model and resulted in further unrepresentative characteristics.

4.3 E -- A.D. Little's criticism of accelerations at the beginning of a subcycle and decelerations at the end of a



Source: Arthur D. Little, Inc.

FIGURE A-1 RESPONSE OF ENGINE SPEED TO A STEP CHANGE IN ENGINE TORQUE AS A FUNCTION OF TIME subcycle is unreasonable. In order to implement a test procedure that is simultaneously representative of actual operation and practical in terms of time required to complete the procedure, assumptions and compromises must be made. Otherwise, the test procedure would be of the same duration as the average truck's working day.

In the issue at hand, EPA sees no alternative to beginning a cycle with an acceleration and ending a cycle with a deceleration. If a truck starts at idle and ends at idle (a reasonable assumption), then an acceleration at the beginning of operation and a deceleration at the end are inherently reasonable assumptions.

A.D. Little then claimed that the "forced" accelerations and decelerations caused the resulting times spent in cruise, acceleration, deceleration, and idle to be unrepresentative. Table 4-1 in the A.D. Little report lists the phase percentages (cruise, acceleration, etc.) for the CAPE-21 data and the chassis subcycles (NYNF, LAF, etc.). A.D. Little concluded that the differences were too large and not representative of the data. However, these conclusions were based upon A.D. Little's incorrect selection of comparative parameters (see 5.3.1 E). A.D. Little's conclusions are invalid. (Were they valid, no indication was given whether they would result in measurable emission discrepancies.)

It should also be noted that A.D. Little's analysis was based on a rather narrow focus. The chassis cycle is the combination of three subcycles, so it would be more logical to compare the combined segment inputs to the overall cycle phase percentages.

4.4 L -- A.D. Little argued that the number of trucks and truck trips was too small to produce a test cycle with the accuracy and precision implied by the EPA and "...which would normally be expected."

4.4 E -- A.D. Little concluded that the number of trucks used in the CAPE-21 project was too small to accurately estimate the true values of the following operational parameters: 1) mean and median truck speed, engine rpm and engine power, 2) percent acceleration, 3) percent cruise, 4) percent deceleration, and 5) percent motoring. The criterion used was the number of trucks necessary, at a 95 percent confidence level, to be within ±2 percent (absolute error) of the true value, or a relative variation of ten percent of the sample mean. EPA will limit its analysis to the number of trucks necessary to estimate the true value.

A.D. Little calculated that over 1,000 trucks would be necessary to achieve a 2 percent absolute error for the N.Y. Non-Freeway Gasoline engine subcycle mean rpm at a 95 percent confidence level. Clearly such a requirement is absurd, providing no allowances for real-world testing budgets. By reducing the confidence level to 90 percent and the absolute error to 10 percent, the number of trucks is reduced to 30! Since 27 trucks were used, three more trucks would be necessary to meet the more reasonable criteria. Table A-2 lists the number of operating parameters for which there were too few trucks tested to meet the specified criteria for confidence level and absolute error.

Three criteria levels were evaluated in Table A-2: 1) the A.D. Little criteria of a 95 percent confidence level with a 2 percent absolute error (EPA's original target criteria), 2) a 95 percent confidence level with a 5 percent absolute error, and 3) a 90 percent confidence level with a 10 percent absolute error.

The calculations for the number of trucks required to achieve each criteria level were done for the six test subcycles A.D. Little used in Tables 4-3 through 4-8 of their report. These cycles include the: 1) Los Angeles Freeway (LAF) chassis cycle, 2) Los Angeles Non-Freeway (LANF) chassis cycle, 3) LAF gasoline engine cycle rpm, 4) LANF gasoline engine cycle rpm, 5) LAF gasoline engine cycle power, and 6) LANF gasoline engine cycle power.

For each cycle, the number of trucks required to achieve the criteria was calculated for each of the seven operating parameters: 1) mean, 2) median, 3) percent acceleration, 4) percent cruise, 5) percent deceleration, 6) percent motoring, and 7) percent idle. This resulted in six cycles with seven operating parameters per cycle, or 42 operating parameters for each criteria level.

Table A-2 lists the number of these 42 operating parameters which did not have the minimum number of trucks necessary to meet the specified criteria.

Twenty-two of the 42 operating parameters did not have the minimum number of trucks required to meet the stringent A.D. Little criteria that the sample values be within ± 2 percent of the true value at a 95 percent confidence level.

Calculations for a more reasonable criterion of a 5 percent error at the same 95 percent confidence level shows that only five of the 42 operating parameters didn't have the minimum number of trucks. As mentioned previously, with a 10 percent error at a 90 percent confidence level, only one parameter didn't have a sufficient number of trucks.

Table A-2

Number of Parameters Requiring
Additional Truck Tests to Meet Criteria

Confidence Level	90%	95%	95%
Absolute Error	10%	5%	2%
No. of Parameters (42 possible)	1	5	22

Considering the costs associated with achieving marginal reductions in absolute error, EPA cannot justify further testing to increase sample size. CAPE-21 was the largest on-road truck usage study ever conducted. It is EPA's judgment that the number of trucks tested was adequate, and that A.D. Little's criticism was unreasonable.

4.5.1 L -- EPA's statistical filter was characterized as incomplete and inconsistently applied. EPA's cycle acceptance criteria neglected the possibility of incorrectly accepting an unrepresentative cycle as representative. Modal percentage measures (percent acceleration, deceleration, cruise, idle) were not included in the computer's statistical filter. The Kolmogorov-Smirnov test (K-S test) was not a sufficient test for comparing cycle and input matrices because the data base was too sparse. In fact, since the distributions of acceleration, deceleration and cruise vary with speed, the K-S assumption of independent identically distributed observations is incorrect. Finally, where generated cycles could not pass EPA's admittedly strict acceptance criteria, the criteria were relaxed to accept the cycle. Therefore, in every engine and chassis test cycle, there is at least 1 percentage measure that differs from its input matrix by more than EPA's 2 percent criteria.

4.5.1 E -- The statistical filter, the theories behind it, and the issues surrounding it are technically complex. The reader is referred to the appropriate reports[10,13] in which the filter's strengths and weaknesses are explained in detail.

To address A.D. Little's criticism of the statistical filter methodology, it is best to review the real practical constraints on cycle generation.

Firstly, the cycles are intended to model an extremely diverse population of trucks. As a case in point, Figure A-2 shows the means of all observed percent rpm's for each individual LA gasoline truck (freeway) varying from 40 to 85 percent. The distribution of truck operational parameters about these means, and throughout the aggregate data base, is continuous and decidedly non-normal. This widely distributed, nonsymmetrical, non-normal distributional characteristic severely limits the statistical tests which can be used to quantitatively compare the population with an empirical sample. If a quantitative measure of representativeness is to be made at all (as opposed to a subjective verification using intuition and engineering judgment), only a non-parametric test is available, of which the K-S test is an applicable example. This fact is independent of the cycle generation technique.

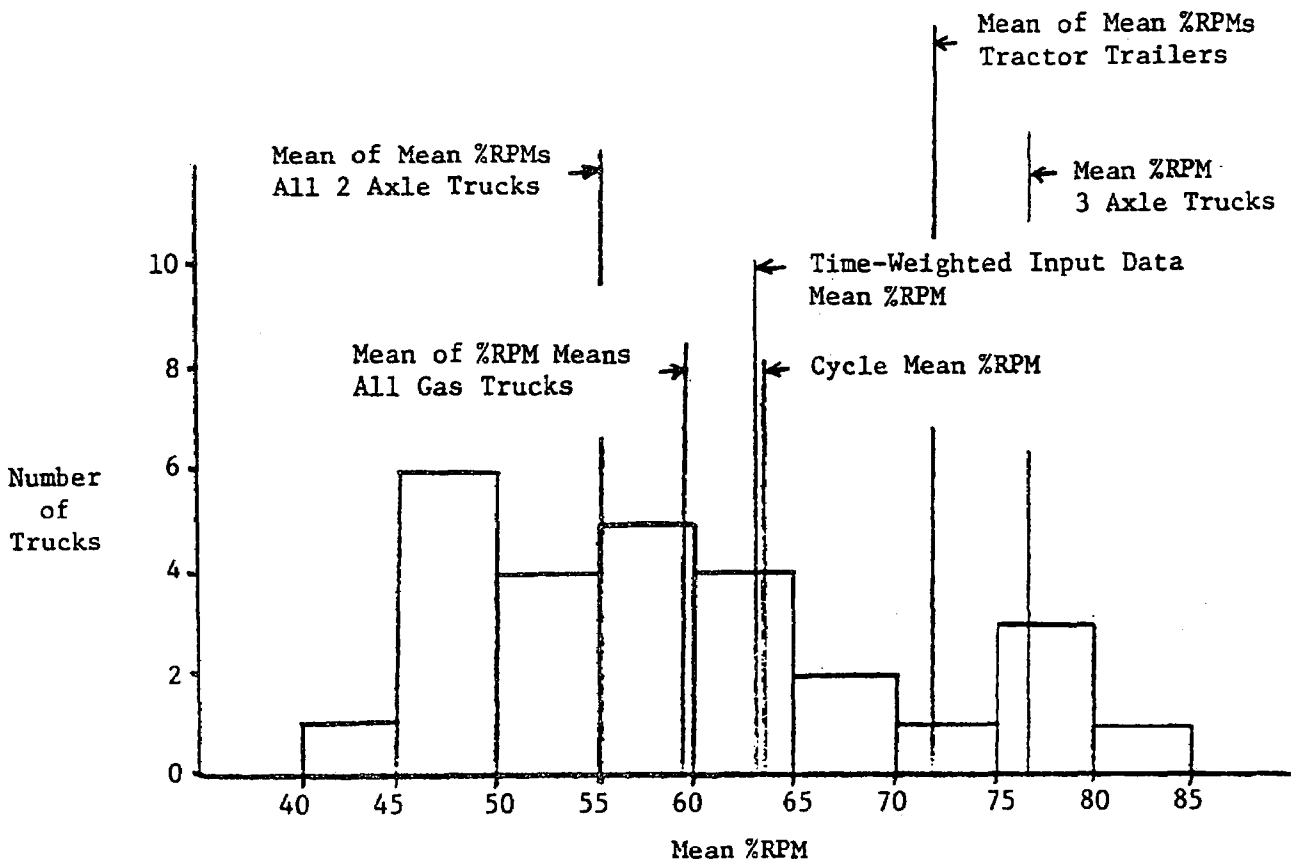


Figure A-2: Mean %RPM Distributions of CAPE-21 Trucks
(LA Freeway - Gasoline)

Secondly, the longer a laboratory emission test procedure runs, the greater the cost, the time, and the overall test burden to accomplish it. The longest test EPA can reasonably impose is on the order of one hour in length. (Note that this is comparable in length to the light-duty Federal Test Procedure (FTP) and the current heavy-duty steady-state tests. Note also that one hour does not include time required for test preparation, vehicle/engine soaking, or data analysis.) Given an overall test procedure consisting of two separate cycles (one cold start, one hot start) and one intermediate soak (pause) period, nominal test cycle length is roughly 20 minutes. Within these 20 minutes all significant truck operational parameters must then be simulated to obtain reasonably representative results. EPA's evaluation of truck operational differences[11,14] indicated that a minimum of 3-4 discrete subcycles are necessary within those 20 minutes for maximum representativeness. In short, 5-7 minutes is the maximum practical length of individual subcycles. If this length implies gross unrepresentativeness, why then are 1-hour tests sufficiently representative for light-duty vehicles, and heavy-duty engines certified on steady-state tests?

Two alternatives exist for cycle generation. Manual selection of truck operational segments from the data base can be done using intuition and engineering judgment, followed by subsequent screening and validation by a statistical filter. On the other hand, a computer can replace the subjective human generator, bringing with it the advantages of infinitely faster sampling and calculation capabilities. In addition, a computer is capable of sampling the data base in a statisticallly representative way using the Monte Carlo technique, i.e.; transitions are probabalistically incorporated into the cycle according to their observed frequency of occurrence in the actual data base. Subjectivity in sampling is eliminated; hence our conclusions above that the Monte Carlo technique is a statistically better means of cycle generation. Consider also that the computerized Monte Carlo method was capable of generating over 10,000 candidate cycles per computer run from a massive second-by-second data base. (For the LAF chassis cycle alone, the CAPE-21 data base was comprised of 1,015,316 individual seconds of operation). The longer the Monte Carlo technique is allowed to probabalistically sample the data base, the better the resulting cycle approximates the input data. A problem arises here because of the practical limitation on laboratory test procedure length. Required cycle times of 5 to 20 minutes are very short compared to the time required for the Monte Carlo technique to sample the entire input data base. The probability of any one 5-minute cycle being representative of the input data is small; large numbers of cycles need to be generated to assure that some of them will in fact be representative. (All of the above is more thoroughly discussed in Reference 10).

Selection of the few representative cycles from this multitude of generated cycles is the function of the statistical filter; as discussed above, the K-S (or other non-parametric) statistical test is the only quantitative alternative. The K-S test, however, is not without weakness. The K-S test, as used in EPA's statistical filter, predicts Type I statistical errors, i.e., the probability that a representative cycle is rejected as nonrepresentative. (As noted in Reference 10, these are acceptable errors, but result in more candidate cycles having to be generated.) Accepting an unrepresentative cycle as representative is referred to as a Type II error. As a means of minimizing this potential error, EPA's methodology deliberately increased the probability of rejecting representative cycles (Type I error). The rationale for this was simply that if one's statistical tests are made stringent enough to reject an increasing number of representative cycles, the probability of accepting unrepresentative cycles is decreased. In addition, target percentage difference criteria between subcycle and input operational parameters were also selected; these target accuracies were characterized by A.D. Little as "very strict."

The higher required probabilities of Type I error resulted in a larger number of cycles having to be generated so that at least a few could pass all six separate K-S tests performed on candidate cycles. As discussed in Reference 10, freeway cycles were more problematic in passing the strict criteria, presumably because of the inhibiting effect of 5-minute subcycle length on comprehensive input data sampling on freeway-type input. Type I probability criteria were in some cases relaxed to allow candidate freeway cycles to be accepted for further screening at EPA.

Further screening was then conducted at EPA based upon a comparative review of operational parameters (e.g., percent acceleration, deceleration, idle, and cruise) for the input and candidate subcycles. The candidate subcycles were ranked numerically according to relative K-S test performance, operational parameter closeness to the input data, and subjective verifications of agreement of subcycle parameter distributions with those of the input data. The best all-around subcycle for each category was then selected.[13] In summary, every possible effort was made to guarantee the representativeness of the final cycles, given the practical constraints of cycle length and available quantitative statistical tests.

The majority of A.D. Little's criticism of EPA's statistical filter focused on "...its incompleteness and the inconsistency with which the statistical criteria are applied." Relaxations of the Type I and percentage difference criteria were claimed by A.D. Little to reflect inconsistency and to have resulted in the acceptance of non-representative parameters for the final cycles. A.D. Little supports this claim by referencing statistical tests elsewhere in its analysis (5.2.1 and 5.3.4). A.D. Little's analysis is incorrect. Their tests made the incorrect assumption that the data were from a normally distributed population, and to compound its error it used the wrong comparative summary percentages for the input data (see 5.2.1 E, 5.3.1 E, and 5.3.4 E of this Appendix). Secondly, A.D. Little's claim of filter incompleteness is based upon the absence of percentage measures for cruise, acceleration, and deceleration from the filter. A.D. Little failed to point out, however, that these percentage measures were indeed used as screening criteria by EPA in selecting the best subcycles from those already generated by the computer.

Another criticism by A.D. Little emphasized that Type II errors were not accounted for in the statistical criteria. EPA concurs that the Type II error probabilities were not calculated, but EPA made efforts to minimize them by increasing the Type I error probabilities by maintaining strict target percentage measure criteria, and by subsequent screening and selection of the final subcycle based upon maximum agreement with the input data.

Two other criticisms made by A.D. Little are judged to be immaterial. A.D. Little argues that since percentage measures vary with engine speed, they are not independent distributions and hence violate the "independent identically distributed (i.i.d)" assumption, thereby rendering the K-S test inapplicable. Secondly, A.D. Little argues that since the cruise submatrix of the LAF subcycle is accepted at the .001 significance level, this implies that "...a cycle as aberrant as the one accepted could be expected to occur only once in every thousand cycles." This is deducing a Type II error probability from a Type I error probability.

The K-S test was merely used as a filter to automate the identification of cycles with parameter distributions similar to the CAPE-21 data base, which it effectively did. Engineering judgment, not statistics, was used in the final comparison of parameter distributions and final selection of test cycles. The question of the percentage measures being from independent distributions is not relevant. The same logic applies to the acceptance of the cruise submatrix for the LAF subcycle at a .001 significance level. Despite the fact that A.D. Little was incorrect in deducing a Type II error probability from a Type I error probability without justification, engineering judgment, not statistics, was the method used to select the best cycle from the several candidate cycles passed by the filter.

In summary, EPA judges A.D. Little's criticism of the statistical filter to be unreasonably strict, although we agree that the filter methodology contains inherent but unavoidable weaknesses. EPA concludes that the final selected subcycles are not as representative as those possible given a drastic (and unacceptable in practice) increase in subcycle length. EPA is confident that sufficient care was taken both in filtering and final screening of the thousands of generated subcycles to assure that those selected are sufficiently representative. A.D. Little failed to substantiate the claim that the subcycles are unrepresentative in the sense that significant emission differences are attributable to the minor discrepancies accepted by the filter.

4.5.2 L -- EPA's use of medians rather than means was incorrect with regard to the number of trips per day, cycle length, and initial idle time. The mean (arithmetic average value) is the more appropriate indicator.

4.5.2 E -- A.D. Little's criticism of EPA's use of medians rather than means, for determining cycle length, initial idle time, and the appropriate fraction of operation characterized by cold starts, was based on opinion, but they failed to substantiate their opinion.

According to E.D. Rothman, Professor of Statistics at the University of Michigan, "The median, , is a preferred measure of location for skewed distributions and coincides with the mean for symmetrical distributions."[22]

A.D. Little's point that the means and medians differ indicates that the distributions are in fact skewed, and therefore makes the median the preferred measure of location, in accordance with accepted statistical practice.

EPA does not agree with Rothman's statement for all situations, but it at least indicates that the median is correct in some cases. The next statement represents a more balanced approach:

"If a measure of central value is being chosen only to describe a set of numbers, a choice between the mean and the median is mainly determined by the interpretation put on the concept of "central." Thus, for example, in buying a large number of bags of grain the mean weight of 100 bags is as useful to the buyer as the weights of the individual bags. However, in a discussion of amounts of money spent by families for milk it may be more useful (from the over-all health viewpoint, if not from the dairy's) to know a median, which specifically pinpoints the dividing line between the upper and lower 50 percent of the families, rather than the mean, which indicates the total amount spent."[24]

Regarding the number of trips per day, cycle length, and initial idle time, EPA prefers the median because it is not biased by a small number of trucks which have substantially different operating parameters than the majority of trucks. The tendency of the mean to be unduly influenced by operation unrepresentative of the majority of trucks makes it unsuitable in this case.

In summary, A.D. Little's accusation that EPA was incorrect in using medians is unjustified. The statistics literature does not support their position.

<u>4.5.3 L</u> -- EPA did not appropriately recognize the large operational differences between cold and hot engine operation. EPA concluded that cold and hot operation were essentially the same, although average operational statistics reveal much less strenuous engine operation when it is cold. Finally, cold engine operation represents an insignificant portion of total truck operation.

<u>4.5.3 E</u> -- Table A-3 was presented by A.D. Little as support for their claim. This table indicates that there are substantial differences between cold operation and the operational parameters for the Los Angeles trucks.

It should be noted that A.D. Little characterized the cold operation versus normal operation for the Los Angeles gasoline trucks as having the "most prominent" difference. But EPA selected the New York Non-Freeway (NYNF) cycle as the first cycle after the cold start, rather than either of the Los Angeles cycles. This allowed EPA to achieve reasonable agreement between the cold operational parameters of the CAPE-21 trucks and those for the transient test procedure without necessitating the development of a seperate cold start cycle.

The limited amount of cold-start data in the CAPE-21 study would not support the development of a separate cold-start cycle that would be reasonably representative. Furthermore,

Table A-3

Statistics Comparing CAPE-21
Cold Operation Versus Normal Operation (Los Angeles)

Statistic	Cold Operation	Normal Operation After Cold Start	Normal Operation After Warm Start	Normal Operation After Normal Start
Average % Power	15	37	51	35
Average % RPM	24	62	73	53
Average % MPH	9	32	38	24
Average % Idle	47	22	20	31

EPA's report entitled "Analysis of Hot/Cold Cycle Requirements for Heavy-Duty Vehicles"[12] concluded that, except for the idle period, there was not a substantial difference in truck operation following a cold, warm, normal, or hot start. Therefore,

> "...it is not necessary to generate unique cold start cycles (engine or chassis) from a matrix containing cold operation only. The sole requirement for a cold start cycle is a longer than normal idle period (approximately 20 seconds) following engine startup."[12]

Table A-4 shows that the cold operation percent idle and the NYNF cycle percent idle differ by only 6 percent. A.D. Little failed to show that EPA's conclusions are incorrect, and that the compromises cause an unrealistic emissions bias. More importantly, A.D. Little fails to show how a separate cold cycle could be developed from the sparse data matrix. Finally, A.D. Little's opinion that cold emissions are insignificant contradicts all emission test experience to date. Table A-5 shows that HC emissions are substantially higher on the cold start portion of the cycle; light-duty vehicle experience substantiates this conclusion.

5.0 <u>Validation of Test Cycles</u>

<u>5.1 L</u> -- Both qualitative (visual inspection of truck parameters) and quantitative (statistical "t-test") measures of cycle representativeness were carried out by A.D. Little in an attempt to validate the test cycles.

<u>5.2.1 L</u> -- EPA conducted no tests of significant differences between the truck data and cycle parameters. Using the CAPE-21 data and the "t-test" (a statistical test which is valid for normally distributed populations) at a 95 percent confidence level, A.D. Little's analysis indicated that seven of nine chassis cycle operational parameters failed the test for representativeness.

<u>5.1-5.2.1 E</u> -- A.D. Little's claim that seven of the nine chassis test cycle parameters are statistically unrepresentative of the CAPE-21 data base was based upon the "t-test." The "t-test," however, assumes that the data is from a normally distributed population. A.D. Little admits that the CAPE-21 truck parameters are not normally distributed, but:

> "...the central limit theorem implies that their means are normally distributed as sample size becomes large. The sample size of 44 trucks is deemed large enough for the parameter means to be normally distributed and tested

Table A-4

Statistics Comparing CAPE-21 Cold Operation to NYNF Test Cycle Operation

Statistic	Cold Operation[23]	NYNF Operation[12]
Average % Power	15	20
Average % RPM	24	12
Average % Idle	47	41

Table A-5

Engine by Engine Transient HC Emission Breakdown

		Cold Start				20 Minute Pause	Hot Start				Composite Test Result	High Medium, or Low Emitter[e]
		1 NYNF	2 LANF	3 LAF	4 NYNF		5 NYNF	6 LANF	7 LAF	8 NYNF		
IHC 446	1[a]	24.73	17.11	15.10	5.55		9.66	11.14	12.53	5.71	-	
	2[b]	23.26	6.97	1.81	5.23		10.65	4.61	1.50	5.36	3.32	H
	3[c]	.289	.188	.166	.061		.677	.736	.830	.373	3.32	
	4[d]	8.7%	5.6%	5.0%	1.8%		20.4%	22.2%	25.0%	11.2%	100%	
IHC 345	1.	25.50	9.09	4.93	3.80		4.82	6.29	4.84	3.40	-	
	2.	64.84	5.51	0.78	5.20		7.14	3.40	0.75	4.38	2.35	M
	3.	.40	.13	.07	.06		.44	.54	.42	.29	2.35	
	4.	17.0%	5.5%	3.0%	2.6%		18.7%	23.0%	17.9%	12.3%	100%	
GM 366	1.	47.86	12.73	5.95	2.61		4.96	4.89	5.07	2.62	-	
	2.	94.7	6.24	0.81	2.69		5.69	2.28	0.69	2.74	2.22	L
	3.	.64	.16	.08	.03		.39	.36	.37	.19	2.22	
	4.	28.8%	7.2%	3.6%	1.4%		17.6%	16.2%	16.7%	8.6%	100%	
GM 350	1.	61.49	12.57	6.42	2.81		4.71	6.50	4.56	2.74	-	
	2.	95.0	6.30	.92	3.06		5.56	3.16	.65	2.95	2.57	M
	3.	.86	.17	.08	.04		.37	.49	.35	.21	2.57	
	4.	33.5%	6.6%	3.1%	1.6%		14.4%	19.1%	13.6%	8.2%	100%	
F 400	1.	32.91	16.16	14.67	6.68		8.62	10.11	13.17	5.69	-	
	2.	46.77	9.66	2.60	9.38		12.10	5.77	2.33	8.02	4.80	H
	3.	.56	.26	.24	.11		.87	.96	1.25	.55	4.80	
	4.	11.7%	5.4%	5.0%	2.3%		18.1%	20.0%	26.0%	11.5%	-	
F 370	1.	20.11	8.13	7.39	1.71		8.05	7.65	6.96	3.46	-	
	2.	52.25	5.29	1.35	2.47		13.37	4.78	1.26	5.02	3.31	H
	3.	.36	.14	.13	.03		.85	.76	.69	.35	3.31	
	4.	10.9%	4.2%	3.9%	.9%		25.7%	23.0%	20.8%	10.6%	100%	

Table A- 5 (cont'd)

Engine by Engine Transient HC Emission Breakdown

		Cold Start				20 Minute Pause	Hot Start				Composite Test Result	High Medium, or Low Emitter
		1 NYNF	2 LANF	3 LAF	4 NYNF		5 NYNF	6 LANF	7 LAF	8 NYNF		
	1.	8.56	7.18	8.22	3.63		10.23	6.41	7.87	3.52	-	
C 360	2.	13.11	3.42	1.08	3.96		13.54	2.99	1.04	3.77	2.45	M
	3.	.11	.09	.10	.05		.80	.47	.58	.28	2.45	
	4.	4.5%	3.6%	4.0%	2.0%		32.7%	19.2%	23.7%	10.2%	100%	
	1.	17.38	10.57	24.67	7.76		10.25	9.32	22.22	9.10	-	
C 440	2.	20.12	4.10	2.78	7.41		11.32	3.65	2.40	8.69	3.81	H
	3.	.19	.11	.26	.08		.67	.57	1.37	.56	3.81	
	4.	5.0%	2.9%	6.8%	2.1%		17.6%	15.0%	36.0%	14.7%	100%	
	1.	16.38	3.88	5.34	1.68		4.94	2.39	4.95	1.57	-	
GM 454	2.	19.06	1.74	.63	1.83		5.82	1.07	0.60	1.72	1.29	L
	3.	.20	.05	.06	.02		.35	.17	.33	.11	1.29	
	4.	15.5%	3.9%	4.7%	1.6%		27.1%	13.2%	25.6%	8.5%	100%	
	1.	47.31	4.33	2.08	1.64		4.12	3.71	1.95	1.83	-	
GM 292	2.	65.65	2.62	0.39	2.08		6.17	2.20	0.37	2.33	2.12	L
	3.	.80	.07	.03	.03		.43	.37	.20	.19	2.12	
	4.	37.7%	3.3%	1.4%	1.4%		20.3%	17.5%	9.4%	9.0%	100%	
	1.	44.54	15.43	6.80	6.43		11.85	6.97	5.65	5.80	-	
GM 454	2.	62.38	75	0.68	5.83		11.24	2.52	0.57	5.25	2.46	M
	3.	.44	.15	.06	.06		.70	.39	.33	.33	2.46	
	4.	17.9%	6.1%	2.4%	2.4%		28.5%	15.9%	13.4%	13.4%	100%	

Table A-5 (cont'd)

Engine-by-Engine Transient HC Emission Breakdown

		Cold Start 1 NYNF	Cold Start 2 LANF	Cold Start 3 LAF	Cold Start 4 NYNF	20-Minute Pause	Hot Start 5 NYNF	Hot Start 6 LANF	Hot Start 7 LAF	Hot Start 8 NYNF	Total Test Composite	High Medium, or Low Emitter	Average HC Emission Level
	1.	21.04	6.13	10.39	3.69		3.66	5.01	9.51	3.71	-		
GM 350	2.	31.48	3.53	1.71	5.34		5.18	2.93	1.57	4.51	2.66	M	
	3.	.34	.09	.16	.06		.34	.46	.87	.34	2.66		
	4.	12.8%	3.4%	6.0%	2.3%		12.8%	17.3%	32.7%	12.8%	100%		
Average: All Engines	4.	17.0%	4.8%	4.1%	1.9%		21.1%	18.4%	21.7%	11.0%	100%	(12 engines)	2.78
Average: High HC Engines	4.	9.1%	4.5%	5.2%	1.8%		20.5%	20.1%	27.0%	12.0%	100%	H (4 engines)	3.81
Average: Med. HC Engines	4.	17.1%	5.0%	3.7%	2.2%		21.4%	18.9%	20.3%	11.4%	100%	M (5 engines)	2.50
Average: Low HC Engines	4.	27.3%	4.8%	3.2%	1.5%		21.7%	15.6%	17.2%	8.7%	100%	L (3 engines)	1.88

(a) Total grams per subcycle.
(b) Grams per brake-horsepower-hour per subcycle.
(c) Subcycle contribution, in effectively-weighted grams per brake-horsepower-hour, to the composite test result. (When added together, all subcycle contributions add up to the composite test result). For methodology, see Reference 17, pp. 4-5.
(d) Relative percentage of subcycle contribution ( ) to the total composite test result.
(e) In grams per brake-horsepower-hour: High (H) $>$ 3.3
3.3 $>$ medium (M) $\geq$ 2.3
Low (L) $<$ 2.2

using a t-distribution. Therefore, the t-test is the appropriate test used for testing the representativeness of all chassis cycle parameters."

A.D. Little was incorrect in its application of the central limit theorem. As Figures A-2, A-3, A-4, A-5, A-6 and A-7 indicate, the individual truck data is decidedly non-normal. Secondly, the central limit theorem can only be invoked for means; most of the data is in the form of percentage measures--not mean values.

Even if the t-test were applicable, A.D. Little made another mistake in selecting the wrong statistics for comparison. A.D. Little used individual truck data, taking means of each parameter for all 44 or 27 trucks. A.D. Little neglected the fact that each truck was instrumented for varying amounts of time, i.e., the aggregate data base consists of effectively time-weighted individual truck data. Even with a completely normal distribution, it would be no surprise if A.D. Little discovered differences between their parameter and the cycles, since the cycles were generated from a different distribution.

Finally, the use of means for validation purposes is insufficient. Any two distributions can be very different yet have the identical mean value. It is the shape of the distribution which is critical, especially with respect to emissions. EPA realized this during cycle development and included K-S tests and engineering evaluations of the cycle distributions.

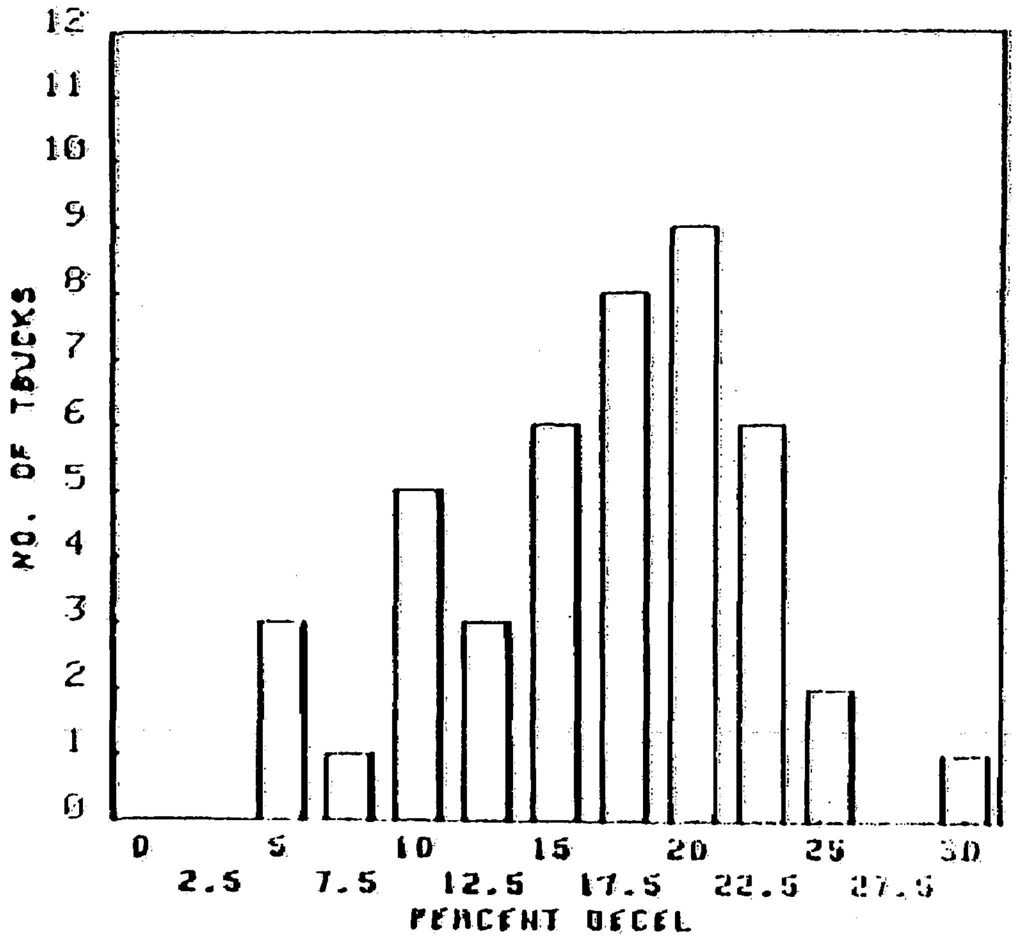
5.2.2 L -- A qualitative review of the CAPE-21 percentage cruise data indicates that the chassis cycles exhibit more cruise than the input data warrants.

5.2.2 E -- In this section, A.D. Little repeats its criticism that the chassis cycle cruise statistics are unrepresentative. As previously discussed, A.D. Little's statistical tests were performed using an incorrect assumption of normality; however, its observation that the percent cruise for the three chassis cycle segments is less than the corresponding percent cruise for the CAPE-21 trucks is correct. The question is whether the operational difference in percent cruise causes a significant difference in emission levels. This question has yet to be addressed, but it has no bearing whatsoever on certification test procedures or regulatory requirements.

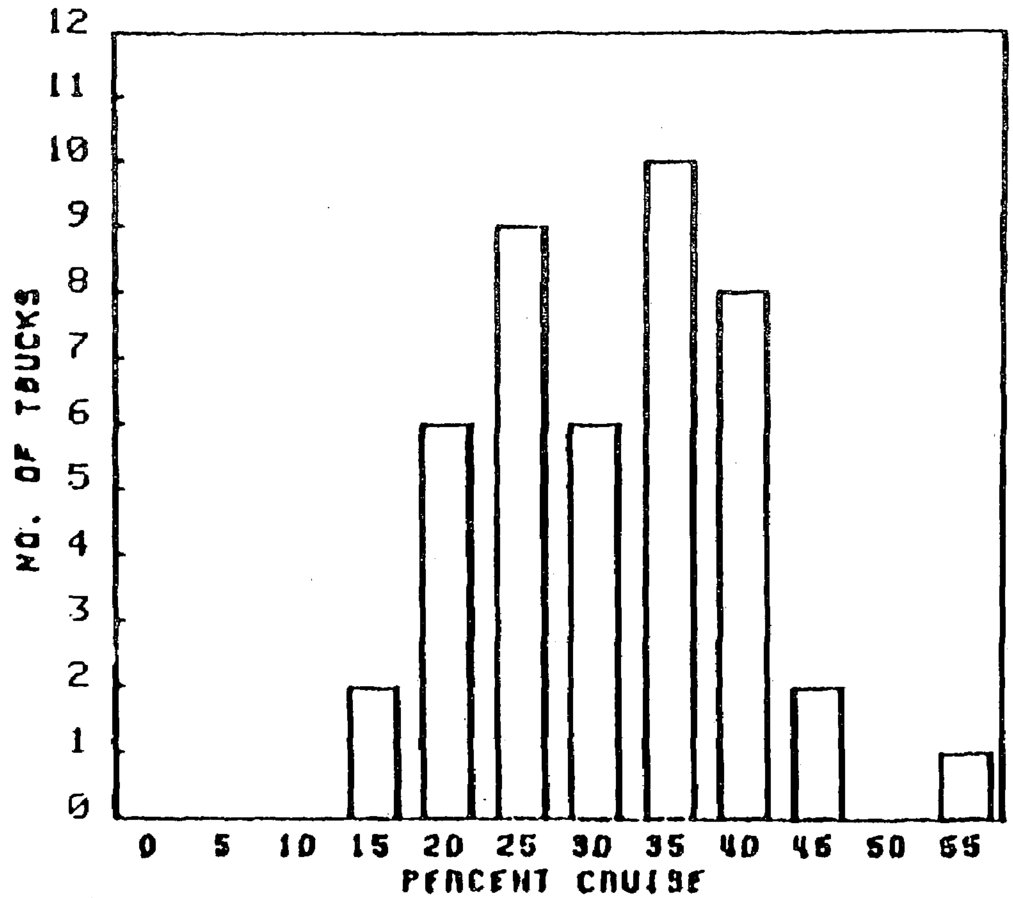
5.2.3 L -- The "t-test" at a 95 percent confidence level is again used to assert that the cycle percentage cruise as

Figure A-3

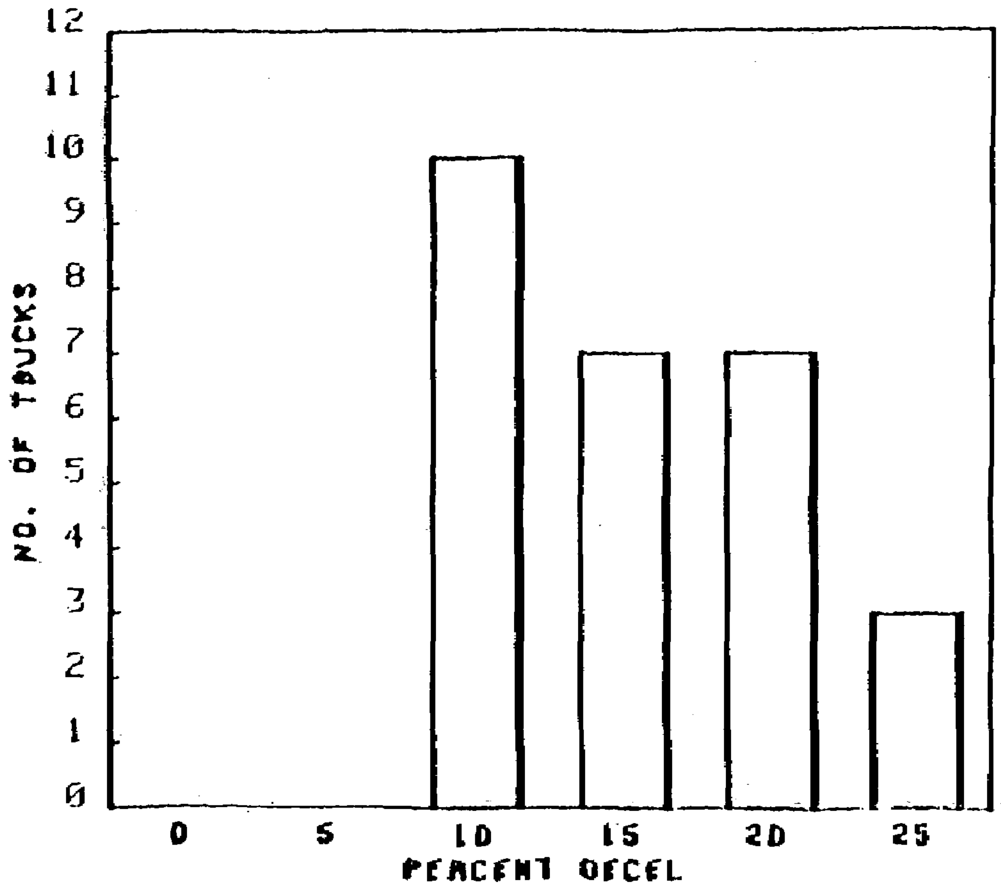
Distribution of Speed % Deceleration
(44 LA Non-Freeway Trucks)



Distribution of Speed % Cruise
(44 LA Non-Freeway Trucks)



Distribution of Power % Deceleration
(27 LA Freeway Gasoline Trucks)



Distribution of Power % Cruise
(27 LA Freeway Gasoline Trucks)

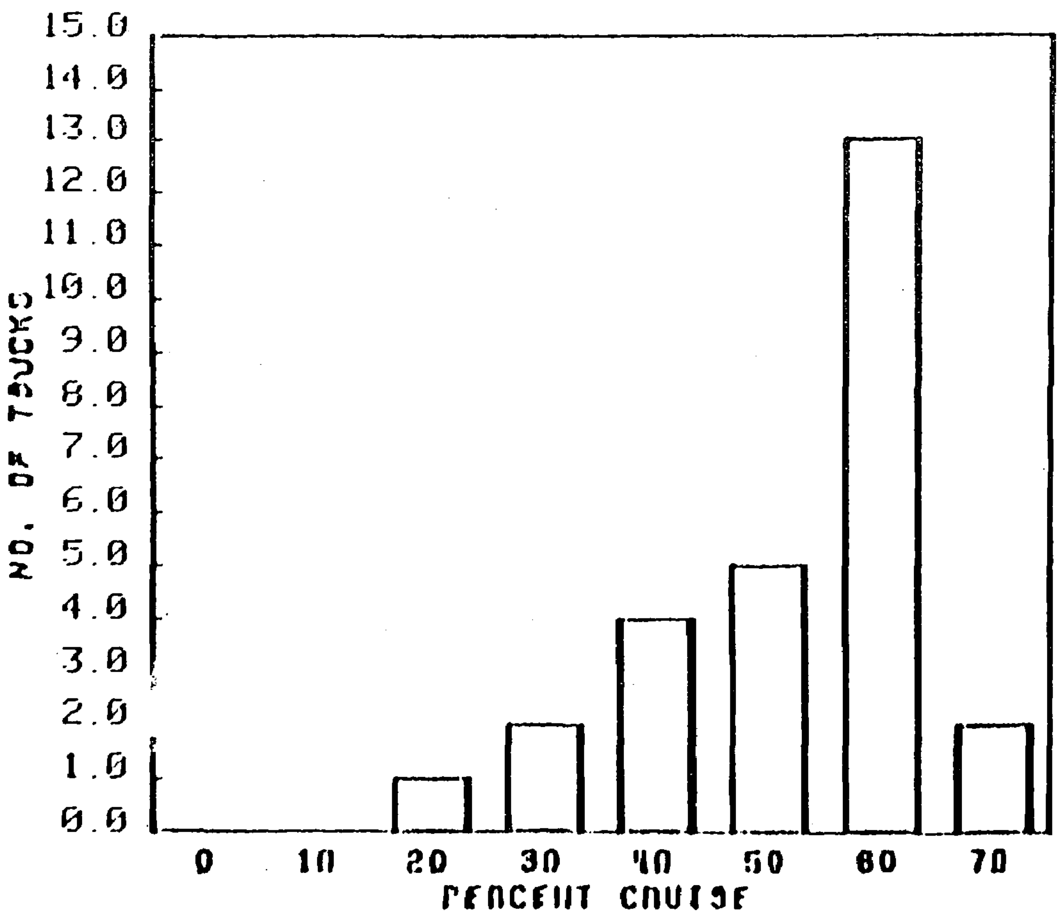
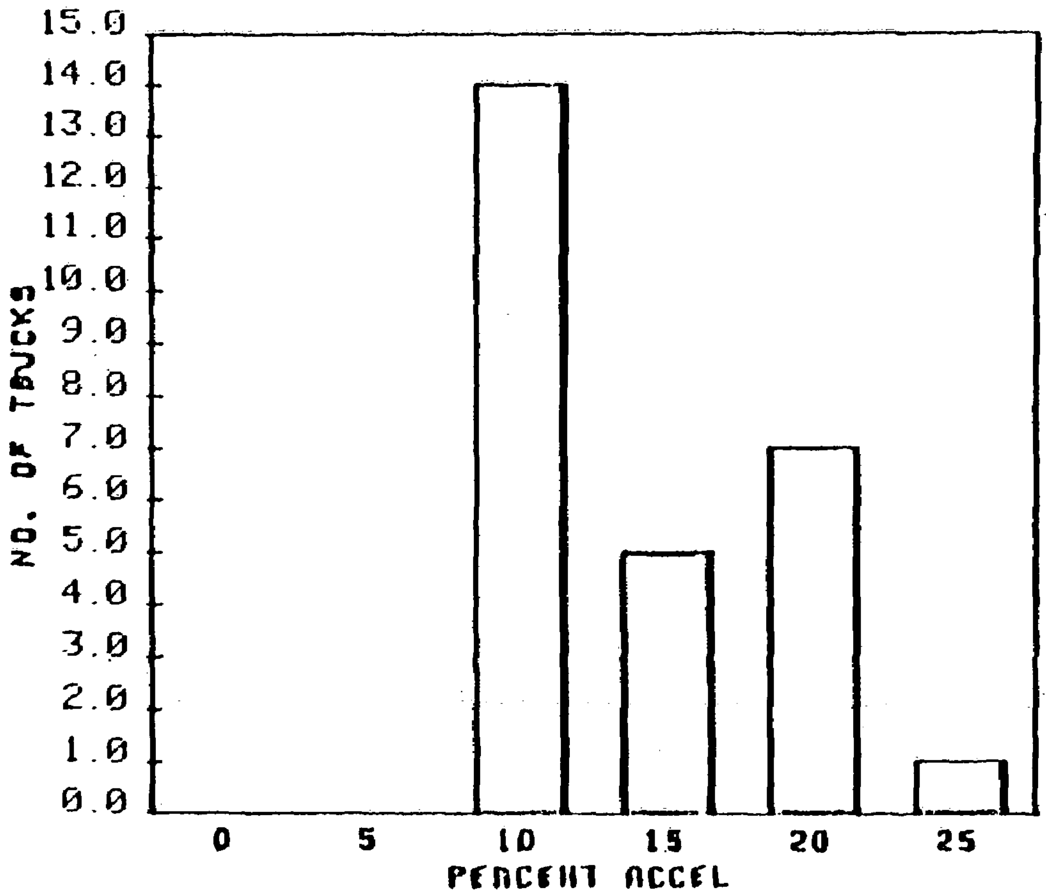


Figure A-7

Distribution of Power % Acceleration
(27 LA Freeway Gasoline Trucks)



developed by EPA for the chassis cycles were not representative. Standardized values of 5.1, 1.6, 2.0 for each cycle were exhibited, when the 95 percent confidence level requires that the standardized value be 1.96 or less.

5.2.3 E -- A.D. Little stated that statistical tests were presented in Section 4.2, but none were found, so we assumed they were referring to the statistical tests presented in Section 5.2 of their report. If so, EPA's analyses, 5.2.1 and 5.2.2, are relevant responses to A.D. Little's claims.

5.2.4 L -- The "t-test" is again used to assert that the individual chassis cycles are too short to be representative primarily because of cold-start implications for short cycles. "...While it is recognized that these trip lenths sometimes combine freeway and non-freeway driving, and that the finalized cycles are 20 minutes (as opposed to 5), the individual cycle segments should be representative of the data."

5.2.4 E -- A.D. Little claimed that the chassis subcycle lengths are too short to be representative, the major difficulty being that "...emissions and engine operational differences which result from cold or thermally unstable engine operations are too high a percentage of total operation."

The issue of cold vs. normal operational differences has been addressed in Section 4.5.3 E of this analysis and will not be repeated here. Concerning the issue of trip length, A.D. Little calculated confidence bounds for NY and LA gas trucks. Again, A.D. Little's statistics are in error! Their calculation is based on the assumption that the data are normally distributed, but as Figures A-8 and A-9 (from Reference 14) show, the distribution of the data does not even remotely resemble a normal distribution. Therefore, their confidence bounds are incorrect.

In addition, even if their 95 percent confidence limits were correct, the chassis cycle length is within their confidence limits for NY gas truck average trip length, and only 0.28 minutes or 17 seconds less than their incorrect 95 percent confidence limits for LA gas truck average trip length. Also, in order to comply with their suggestion that the subcycle lengths should be equivalent to the CAPE-21 trip lengths, the chassis trip length would have to be expanded to the equivalent of six consecutive truck trips. This would sextuple the test burden, but no emissions data were supplied to justify the additional burden.

5.3 L -- The gasoline engine cycles were also determined to be unrepresentative, by virtue of the fact that the cycles

Figure A-8

TIME PER TRIP DENSITY FUNCTION FOR NY GASOLINE

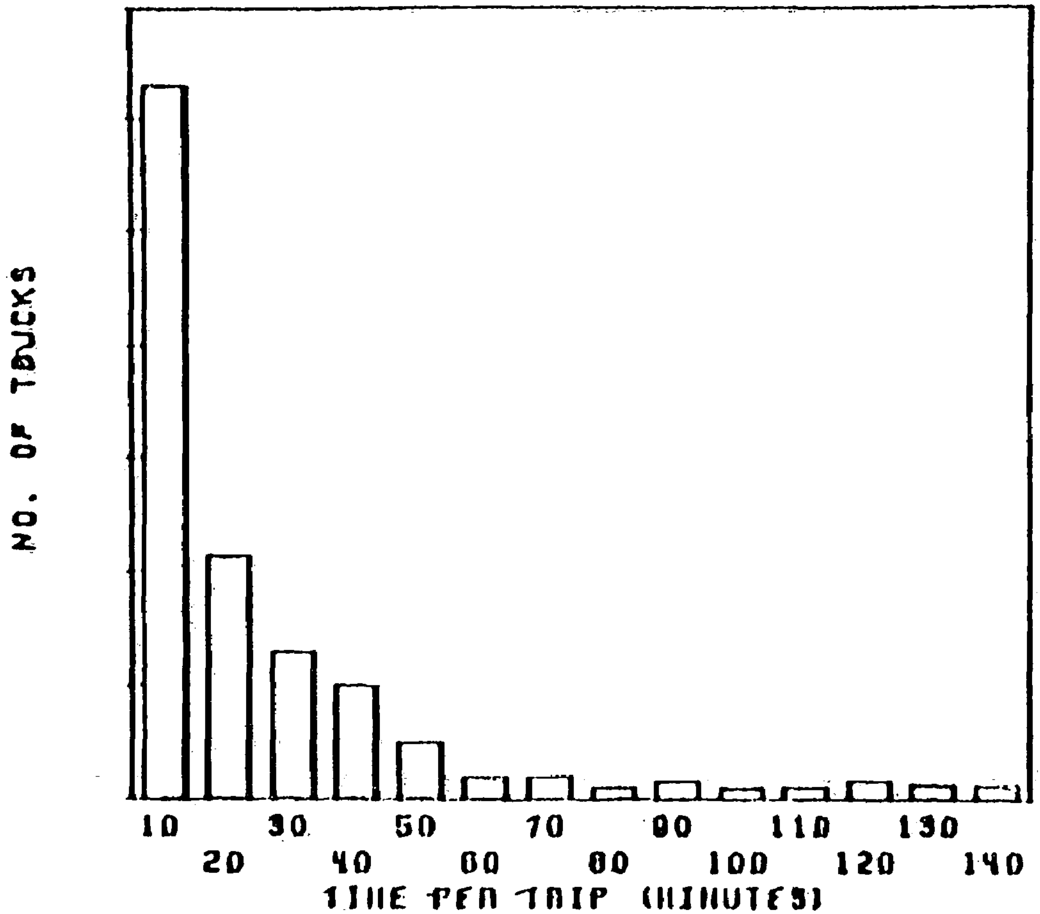
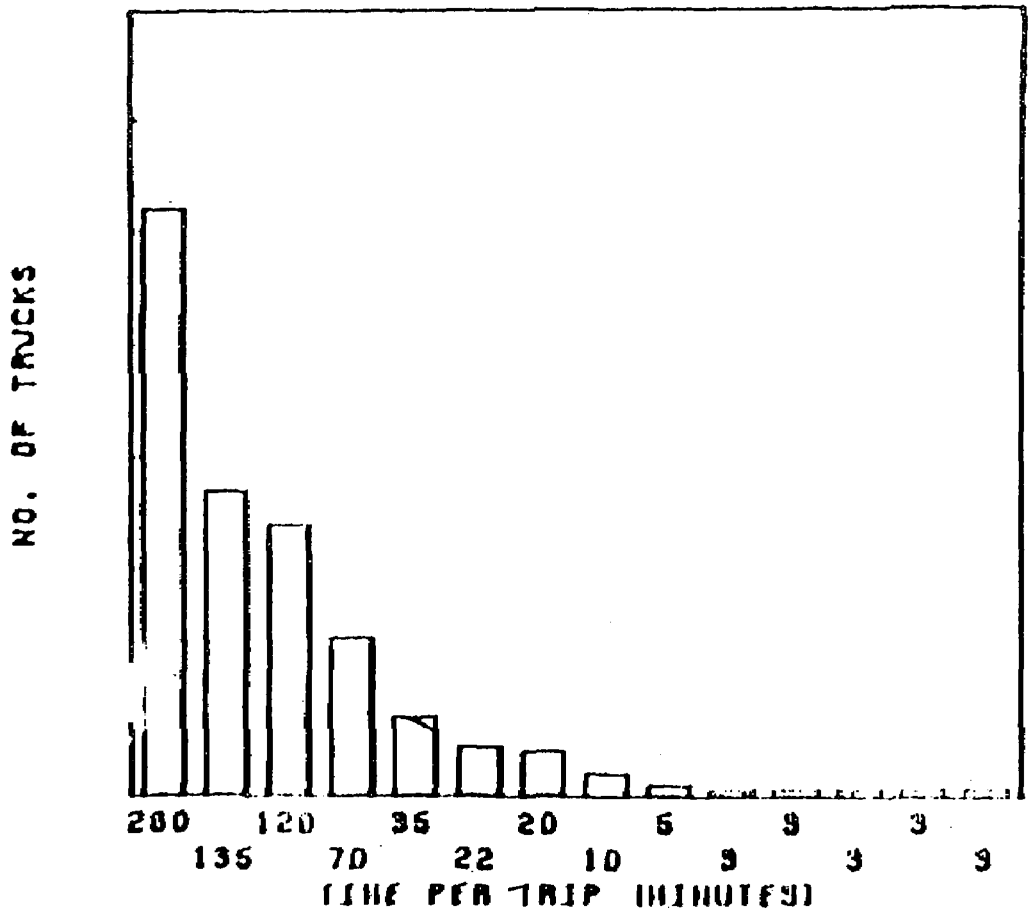


Figure A-9

TIME PER TRIP DENSITY FUNCTION FOR LA GASOLINE



were too short, mean and median rpm values for the LA Freeway cycle were too high, the correlation of percent power with percent rpm for the LANF cycle is not consistent with the CAPE-21 data, the LAF rpm exhibited higher variability than the data base, and both LA cycles contained unrepresentative parameters.

5.3 E -- EPA's analysis of the engine subcycle length is virtually identical to that presented earlier on the chassis subcycles. In general, the overall test cycle is a nominal 20 minutes in length; within that 20 minutes the freeway/non-freeway operations are appropriately weighted. With respect to the individual subcycles, a 5-minute length is only a problem if the Monte Carlo technique was unable to sample the entire data base within that time, and the statistical filter was unable to screen out the unrepresentative subcycles. Subcycle lengths of 5, 10, and 20 minutes were generated during the CAPE-21 cycle generation program to evaluate this very issue; subcycle lengths beyond 5 minutes minimally improved the agreement of subcycle parameters with the input data parameters. Finally, it is nonsense to argue that a predictive engineering test procedure must be as long in time as the phenomenon it is intending to model. The overall test procedure is, nevertheless, very close in length to the trip length of the average truck (as derived by median trip length).

5.3.1 L -- "The LA Freeway engine cycle appears to have a disproportionate percentage of high power and high RPM's,... thus the RPM profile of the LA engine cycle was not representative of the individual truck data."

5.3-5.3.1 E -- We can summarize A.D. Little's arguments that the LAF engine subcycle contains disproportionate percentages of high power and high speed by saying that their analysis is incorrect and incomplete. EPA's own review indicates that the LAF engine subcycle contains about 12 seconds more WOT/WOT-equivalent power operation than the CAPE-21 data base indicates. The impact on composite cycle emissions is small, representing a maximum overstatement of CO emissions of approximately 5 percent, and a maximum understatement of NOx emissions of 3 to 6 percent. This small percentage emissions discrepancy arises from the most operationally sensitive mode of engine operation.

A.D. Little used mean rpm's of the individual LAF trucks as the comparative indicator of subcycle agreement with the data base. A.D. Little argued that since "...only 6 out of the 27 gasoline trucks had mean RPM values exceeding the cycle mean rpm values,...the rpm profile of the LA engine cycle was not representative of the individual truck data." Table A-6 presents summary data for the 27 LA gasoline trucks. Note immediately that nine exceed the mean cycle percent rpm, instead of A.D. Little's six. More significantly, note that A.D. Little ignored the fact that the aggregate data base not only included all 27 trucks, but also varying amounts of data for each truck, i.e., the trucks were instrumented for varying amounts of time, and each spent varying amounts of time on the freeway. (The hours of measured operation per truck are also presented in Table A-6). The subcycle was generated from the aggregate data base, effectively time-weighting the individual truck mean percent rpm values. Time-weighting each individual truck mean yields a mean percent rpm value of 62.82 (as opposed to the unweighted mean of individual truck means of 59.5.) In short, the higher speed trucks spent more time on the freeway, or conversely, more time on the freeway led to a greater proportion of higher speeds being recorded. Figure A-2 presents the non-normal distribution of mean percent rpms for the individual trucks (un-timeweighted). Note that there is an approximately 1 percent difference between the subcycle mean percent rpm (63.52) and that of the aggregate data. In a population whose mean percent rpm's vary from 42 to 85, a 1 percent difference between the subcycle and CAPE-21 means is trivial. However, a mean or median value is only a gross indicator of a population's overall distribution. A.D. Little referenced a comment by International Harvester that the LAF engine cycle contains "...a disproportionate percentage of high power and high percent rpm's." EPA concurs with this observation, but believes it to be inconsequential to the overall representativeness of the test procedure.

In the EPA report[13] in which the candidate engine cycles were screened and reviewed and the final cycles adopted, it was recognized that within the final LAF subcycle "...there is slightly more operation in the higher power range than might be desirable." This is evident in Figures A-10 and A-11 in which the %Power and %rpm are presented. Also presented, based upon the subcycle length of 316 seconds, are the times spent in each segment of operation for the actual subcycle, and for a theoretical subcycle identical to the CAPE-21 data.

We note immediately from Figures A-10 and A-11 that the additional time spent at high speeds and high power is small relative to the entire subcycle length (9 seconds, or 2.8 percent of the total 316 seconds, for speeds greater than 97 percent; 15 seconds, or 4.7 percent, for engine torques greater than 85 percent). If this small additional time were reallocated into more appropriate parts of the distribution, there would have to be a drastic difference in emission rates between the original speed or torque and the new speed or

Table A-6

Los Angeles Freeway Truck Data

Gasoline Truck Data		Hours of Measured Operation Per Truck	
Truck No. (Type)	Freeway Mean %RPM	Combined	Freeway Only
5 (2 axle)	62.8	7.0	.7
7 (2 axle)	55.8	17.1	.8
10 (2 axle)	52.6	14.0	5.4
11 (2 axle)	64.1 (x)	22.7	14.1
13 (2 axle)	58.8	15.4	.2
14 (2 axle)	47.5	15.6	8.1
17 (2 axle)	78.1 (x)	6.5	2.4
19 (2 axle)	51.5	12.6	6.1
21 (2 axle)	54.3	12.5	4.2
24 (2 axle)	49.1	10.4	2.9
25 (2 axle)	47.1	16.0	8.8
26 (2 axle)	41.9	9.2	3.8
28 (2 axle)	61.7	8.4	2.0
30 (2 axle)	45.6	8.2	.5
32 (2 axle)	59.1	6.0	3.3
36 (2 axle)	47.5	1.7	.2
40 (2 axle)	66.0 (x)	9.5	4.9
42 (2 axle)	56.5	6.1	2.7
47 (2 axle)	46.1	14.7	7.7
35 (3 axle)	76.7 (x)	15.6	4.6
2 (tractor-trailer)	52.1	9.0	1.3
3 (tractor-trailer)	64.6 (x)	10.5	3.4
8 (tractor-trailer)	74.6 (x)	15.7	6.0
12 (tractor-trailer)	78.3 (x)	20.0	13.4
39 (tractor-trailer)	85.4 (x)	20.4	13.4
43 (tractor-trailer)	68.1 (x)	7.8	5.2
8 (tractor-trailer)	59.6	11.3	3.7

Summary

LA Freeway Engine Cycle Mean RPM: 63.52

Time-Weighted Freeway Truck Mean RPM (or, Mean RPM of the Aggregate Gas LA Freeway Data Base): 62.82

Mean of Individual Truck Mean RPM: 59.50

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* Calculated from the ratio of freeway records to combined records, multiplied by total hours of operation.

(x) Denotes trucks with mean RPMs higher than LAF engine cycle mean RPM.

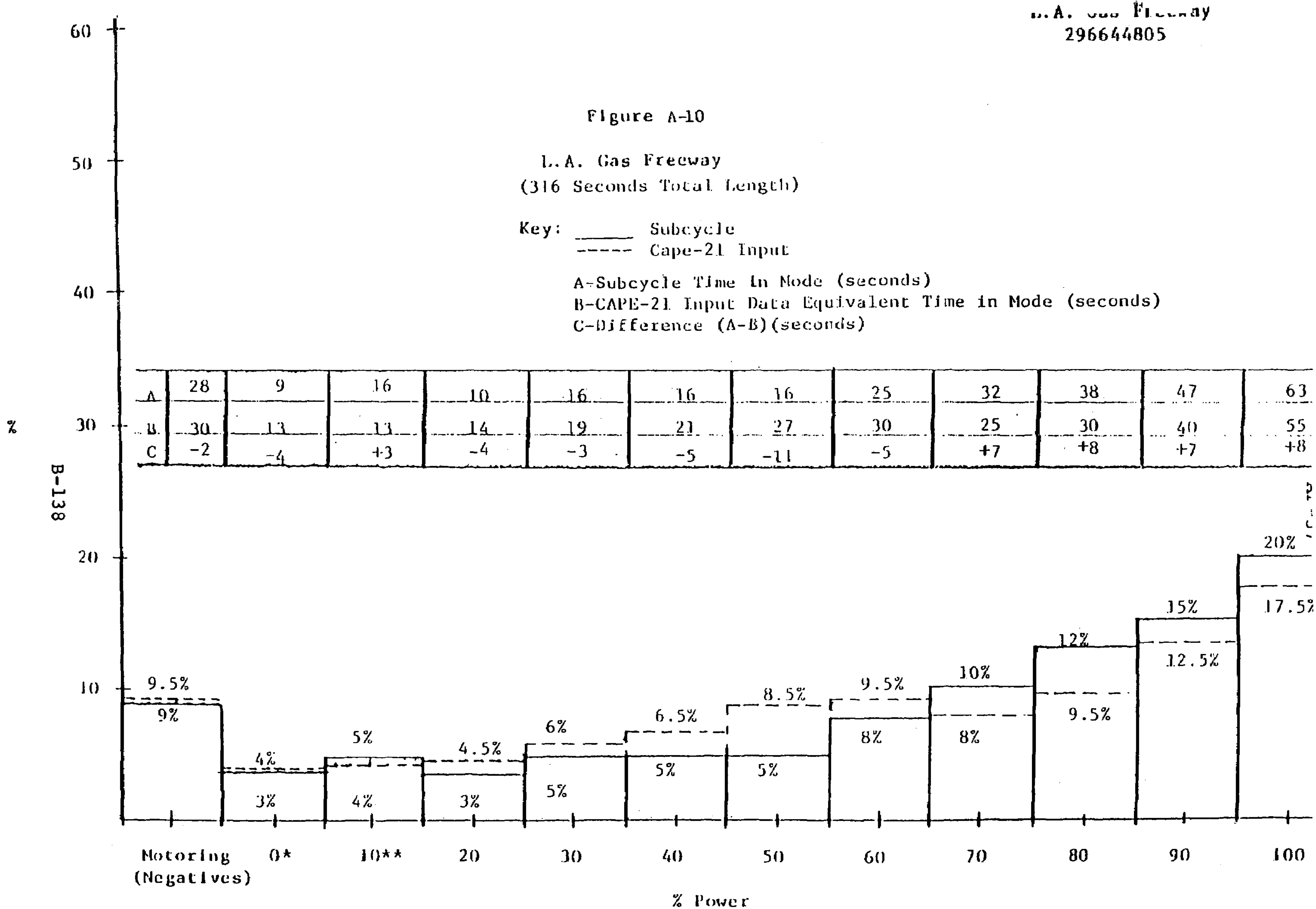
Figure A-10

L.A. Gas Freeway
(316 Seconds Total Length)

Key: ______ Subcycle
----- Cape-21 Input

A-Subcycle Time in Mode (seconds)
B-CAPE-21 Input Data Equivalent Time in Mode (seconds)
C-Difference (A-B)(seconds)

	Motoring	0*	10**	20	30	40	50	60	70	80	90	100
A	28	9	16	10	16	16	16	25	32	38	47	63
B	30	13	13	14	19	21	27	30	25	30	40	55
C	-2	-4	+3	-4	-3	-5	-11	-5	+7	+8	+7	+8

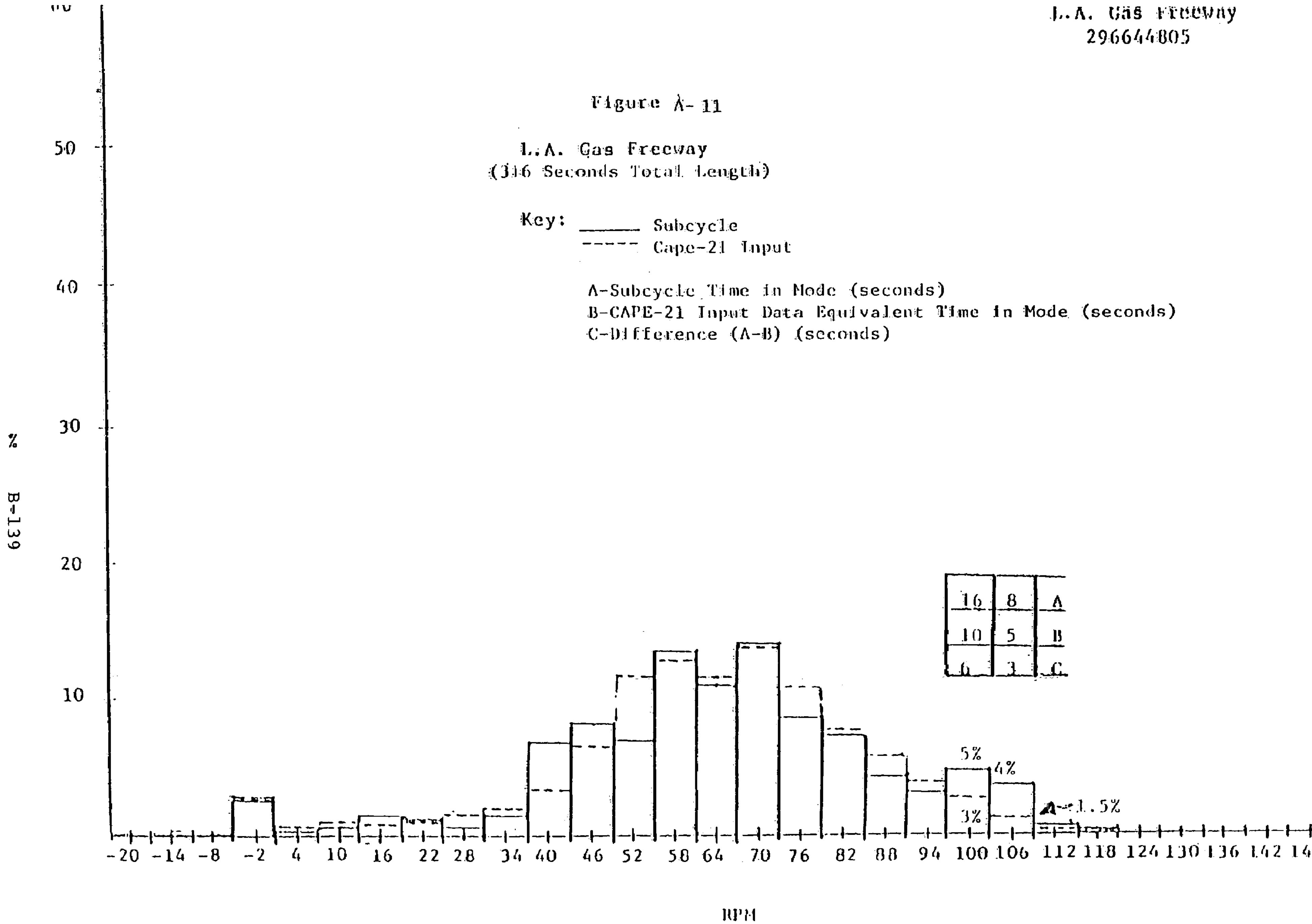


* 0 ≤ % < 5

** 5 ≤ % < 15

Figure A- 11

L.A. Gas Freeway
(316 Seconds Total Length)



torque for the reallocation to produce a measurable difference in overall subcycle emissions. Somewhat greater differences would be required to produce a measurable change in composite test cycle emissions.

This analysis will assume that the misproportion of rpms will have insignificant effects on composite cycle emissions, while torque misproportions are potentially large enough to justify further study. The rpm assumption is based upon three facts: 1) earlier published data[17] indicated that composite test cycle emissions were minimally affected by proportional changes in the RPM schedule, 2) no theoretical engineering reason exists to explain why a drastically different brake specific emission rate would exist at higher speeds, and 3) observation of steady-state emission data presented in Table A-7. (Note in Table A-7 that emission rates do change from speed-to-speed, but not to the extent which would cause the 9 seconds of differential emissions--representing 2.8 percent of the subcycle and 0.8 percent of the composite cycle--to measurably alter composite cycle emissions.) On the other hand, torque significance is assumed on the basis of three observations: 1) earlier published data[17] indicated that composite test emissions were measurably affected by proportional changes in the torque schedule, 2) theoretical reasons for drastic emission changes do exist, i.e., power valve fuel enrichment above 90 percent torque, and 3) significant differences are in fact observed in the steady-state data presented in Table A-7. Changes in emissions rates between wide-open throttle (WOT) (100 percent torque) and torques less than 90 percent (non-WOT loads), as approximated from Table A-7 are:

	Average Factor of Increase	Maximum Factor of Increase	Minimum Factor of Increase
BSHC	2.5	11.0	0.8
BSCO	16.6	43.8	7.9
BSNOx	0.44	0.81	0.29

Note that numbers less than 1.0 represent a decrease in WOT emission rates relative to non-WOT rates.

The remainder of the analysis will concentrate only on BSCO emissions because: 1) as indicated above, they are affected most by WOT operation, and 2) as indicated in Tables A-5 and A-8, the LAF subcycle is the major contributor of BSCO emissions to the composite test results, whereas it is a minor contributor of HC emissions. In short, if the misallocated torque points in the LAF subcycle cause a net change in composite emissions, that change will be most strongly observed in composite BSCO emissions.

Table A-7

Steady-State Brake Specific
Emissions of a Current Technology HDG Engine*

BSHC**

RPM/%Load	100%	75%	50%	25%
3600	.33	.28	.03	.08
3100	.26	.06	.17	.04
2600	.22	.03	.07	.26
Average:	.27		.11***	
Maximum Value:	.33		.28	
Minimum Value:	.22		.03	

BSCO**

RPM/%Load	100%	75%	50%	25%
3600	81.5	1.86	2.14	4.00
3100	68.5	2.00	4.33	6.45
2600	59.1	3.61	6.08	7.44
Average:	69.7		4.21	
Maximum Value:	81.5		7.44	
Minimum Value:	59.1		1.86	

BSNOX**

RPM/%Load	100%	75%	50%	25%
3600	3.22	11.2	9.17	7.56
3100	3.99	10.6	10.2	6.92
2600	4.62	9.70	9.07	5.67
Average:	3.94		8.90	
Maximum Value:	4.62		11.2	
Minimum Value:	3.22		5.67	

* 1978 California IHC 404.
** Grams/brake-horsepower hour.
*** Represents the average of all non-100 percent emission rates.

Table A-8

Engine-by-Engine Transient CO Emission Breakdown

		Cold Start				20-Minute Pause	Hot Start				Composite Test Result	High Medium, or Low Emitter[e]
		1 NYNF	2 LANF	3 LAF	4 NYNF		5 NYNF	6 LANF	7 LAF	8 NYNF		
IHC 446	1[a]	236.4	245.2	774.8	127.2		123.3	200.0	708.1	122.7	-	
	2[b]	222.4	99.9	93.0	119.9		135.9	82.7	84.7	115.1	92.88	H
	3[c]	2.79	2.73	8.63	1.42		8.73	13.3	47.1	8.20	92.68	
	4[d]	3.0%	2.9%	9.3%	1.5%		9.4%	14.3%	50.7%	8.8%	100%	
IHC 345	1.	90.3	84.7	153.2	60.0		39.7	60.2	150.6	56.1	-	
	2.	229.6	51.4	24.2	79.2		58.9	32.5	23.2	72.3	32.8	L
	3.	1.40	1.24	2.24	.88		3.70	5.29	13.11	4.94	32.8	
	4.	4.3%	3.8%	6.8%	2.7%		11.3%	16.1%	40.0%	15.1%	100%	
GM 366	1.	143.7	140.7	187.7	86.1		88.0	113.3	167.0	88.2	-	
	2.	284.3	69.1	25.5	88.8		100.8	52.9	22.8	92.1	41.9	L
	3.	1.9	1.8	2.4	1.1		6.9	8.7	12.5	6.6	41.9	
	4.	4.5%	4.3%	5.7%	2.6%		16.5%	20.8%	29.8%	15.8%	100%	
GM 350	1.	171.2	155.2	404.5	102.6		111.6	130.2	376.6	95.3	-	
	2.	264.5	77.7	57.8	116.6		131.9	63.4	53.9	102.5	67.8	M
	3.	2.4	2.1	5.3	1.4		9.3	10.1	29.7	7.4	67.8	
	4.	3.5%	3.1%	7.8%	2.1%		13.7%	14.9%	43.8%	10.9%	100%	
F 400	1.	222.9	2.4	620.6	130.6		103.5	161.6	582.3	127.3	-	
	2.	316.7	97.0	109.9	183.5		145.4	92.2	103.0	179.6	113.2	H
	3.	3.8	2.6	10.0	2.1		10.6	15.6	56.2	12.3	113.2	
	4.	3.4%	2.3%	8.8%	1.9%		9.4%	13.8%	49.6%	10.9%	100%	
F 370	1.	85.2	106.6	230.7	21.4		38.8	80.1	206.7	40.3	-	
	2.	221.5	69.4	42.1	30.9		64.4	50.0	37.4	58.4	45.0	L
	3.	1.5	1.8	3.9	.4		4.2	8.1	21.0	4.1	45.0	
	4.	3.3%	4.0%	8.7%	.9%		9.3%	18.0%	46.7%	9.1%	100%	

Table A-8 (cont'd)

Engine-by-Engine Transient CO Emission Breakdown

		Cold Start 1 NYNF	Cold Start 2 LANF	Cold Start 3 LAF	Cold Start 4 NYNF	20-Minute Pause	Hot Start 5 NYNF	Hot Start 6 LANF	Hot Start 7 LAF	Hot Start 8 NYNF	Composite Test Result	High Medium, or Low Emitter
	1.	107.5	144.7	868.6	61.2		56.6	127.9	783.0	58.5	-	
C 360	2.	164.7	68.8	113.8	66.7		76.3	59.5	103.3	62.6	92.0	H
	3.	1.4	1.8	10.8	.8		4.6	9.6	58.6	4.4	92.0	
	4.	1.5%	2.0%	11.7%	.9%		5.0%	10.4%	63.7%	4.8%	100%	
	1.	228.3	203.6	1262.0	100.6		75.2	161.1	1217.2	94.1	-	
C 440	2.	264.3	78.9	142.1	96.0		83.0	63.0	131.7	89.9	115.6	H
	3.	2.5	2.1	13.1	1.0		5.0	10.0	75.9	5.9	115.6	
	4.	2.2%	1.8%	11.3%	.9%		4.3%	8.7%	65.7%	5.1%	-	
	1.	250.3	86.2	769.6	65.2		86.9	102.8	714.1	69.7	-	
GM 454	2.	291.3	38.7	91.3	71.1		102.4	45.8	87.2	76.2	81.9	M
(Short	3.	3.1	1.0	9.0	.8		6.4	7.2	49.5	4.9	81.9	
Block)	4.	3.8%	1.2%	11.0%	1.0%		7.8%	8.8%	60.4%	6.0%	100%	
	1.	315.0	115.7	159.4	64.7		89.4	111.0	161.5	70.0	-	
GM 292	2.	437.1	69.9	30.2	81.9		133.7	65.9	30.5	89.1	55.0	L
	3.	5.6	2.0	2.7	1.1		9.6	11.2	16.3	7.1	55.0	
	4.	10.2%	3.6%	4.9%	2.0%		17.5%	20.4%	29.6%	12.9%	100%	
	1.	204.8	175.6	376.1	144.6		153.9	157.1	366.2	138.2	-	
GM 454	2.	286.9	65.5	37.9	131.1		146.1	56.7	36.9	124.9	55.9	L
(Tall	3.	2.1	1.7	3.6	1.4		9.3	9.0	20.9	7.9	55.9	
Block)	4.	3.8%	3.0%	6.4%	2.5%		16.7%	16.1%	37.4%	14.1%	100%	

Table A-8 (cont'd)

Engine-by-Engine Transient CO Emission Breakdown

		Cold Start				20-	Hot Start				Total	High
		1	2	3	4	Minute	5	6	7	8	Test	Medium, or	
		NYNF	LANF	LAF	NYNF	Pause	NYNF	LANF	LAF	NYNF	Composite	Low Emitter	
	1.	196.1	108.9	805.5	68.1		92.1	104.8	640.8	64.8	-		
GM 350	2.	293.3	62.6	132.21	98.6		130.1	61.4	106.0	78.8	101.5	H	
	3.	3.2	1.7	12.1	1.1		8.5	9.7	59.2	6.0	101.5		
	4.	3.2%	1.7%	11.8%	1.1%		8.4%	9.6%	58.3%	5.9%	100%		
													Average HC Emission Lev
Average All Engines	4.	3.9%	2.8%	9.5%	1.7%		10.7%	14.2%	47.9%	9.9%	100%	(12 engines)	75.7
Average High CO Engines	4.	2.6%	2.1%	12.6%	1.2%		7.1%	11.1%	56.3%	7.0%	100%	(5 engines)	105.5
Average Med CO Engines	4.	3.7%	2.2%	9.4%	1.6%		10.8%	11.9%	52.1%	8.5%	100%	(2 engines)	74.9
Average Low CO Engines	4.	5.2%	1.7%	6.5%	2.1%		14.3%	18.3%	36.7%	13.4%	100%	(5 engines)	46.1

[a] Total grams per subcycle.
[b] Grams per brake-horsepower-hour per subcycle.
[c] Subcycle contribution, in effectively-weighted grams per brake-horsepower-hour, to the composite test result. (When added together, all subcycle contributions add up to the composite test result). For methodology, see Reference 17, pp. 4-5.
[d] Relative percentage of subcycle contribution (c) to the total composite test result.
[e] In grams per brake-horsepower-hour: High (H) > 90
90 ≥ medium (M) ≥ 60
Low (L) < 60

Since the power valves of HDG engines are typically calibrated to provide fuel enrichment somewhere above 90 percent torque, we shall be conservative and denote all torques above 90 percent as WOT-equivalent, with an average value of 95 percent torque. All other torques within the subcycle shall be represented by a constant emission rate (y grams per hour) at an average value of 50 percent torque. Referring to Figure A-11, we note that approximately 12 more WOT-equivalent points are included in the subcycle than the CAPE-21 data indicate. We also assume that 95 percent torque/WOT-equivalent points produce 40 times the emissions (40y grams/hr) than non-WOT emissions. This represents a 21-fold increase in brake specific emission rate, somewhat higher than the average observed for BSCO in Table A-7, over that of the nominal non-WOT/50 percent torque emission rate. Inherent in the analysis is the assumption that all non-WOT modes exhibit effectively equal brake-specific emission rates. (This is not actually the case, but differences are small enough relative to WOT-equivalent emissions that non-WOT brake-specific emission rates can be approximated as equal for our purposes.) Anticipated percentage reductions in BSCO emissions are calculated in Exhibit A-1, assuming substitution of 12 non-WOT (50 percent power) points for the 12 extra WOT-equivalent points.

Exhibit A-1 predicts a theoretical 4-7 percent decrease in BSCO emissions by resubstitution of the 12 WOT-equivalent points. Similar calculations predict a 1.2 percent reduction for BSHC (assuming an average 5-fold increase in grams/hour HC emissions for WOT-equivalent points, and an average LAF subcycle contribution of 25.8 percent from Table A-5), and a 1.0 percent increase in BSNOx (assuming an average grams/hour decrease of 28 percent, an assumed contribution of 25 percent).

These predictions can be tested experimentally by referring to Reference 17, wherein regression equations were developed to model observed behavior of HDG emissions over the actual transient test procedure when the composite cycle torque schedule was proportionally changed. Referring to Exhibit A-1, STEP 2, resubstitution of the 12 points results in a drop in subcycle brake horsepower-hour of 2.7 percent. Note that a 2.7 percent decrease in all 316 subcycle torques will reduce a certain number of torques originally above 90 percent to below 90 percent. In fact, all torques between 90 and 92.5 percent, originally producing WOT-equivalent emissions will now lie below 90 percent and produce non-WOT emissions. Referring again to Figure A-11, the number of torques in the subcycle originally between 90 percent and 92.5 percent is approximately 12 (one-fourth of 47). (We must point out that the power valve may actually be activated at 93 percent torque, as opposed to

Exhibit A-1: Calculated Changes in Composite Cycle Emission Results

Step 1: Calculate Mass Emission Reductions

y = grams/hr, non-WOT torques(average value = 50%)
$40y$ = grams/hr, WOT-equivalent torques(average value = 95%)

LAF Subcycle: Total grams of emissions $= y\left(\frac{316 - 87}{3600}\right) + 40y\left(\frac{87}{3600}\right)$,

where 87 seconds (from Figure A-10) represent the present number of WOT-equivalent points, 316 represents the total subcycle length in seconds, 3600 represents seconds per hour.

Therefore, total grams of emissions = 1.030y grams

Substituting 12 seconds of non-WOT for 12 seconds of WOT-equivalent yields a new emission rate:

$$\text{New Emissions, in Total Grams} = y\left(\frac{316 - 87 + 12}{3600}\right) + 40y\left(\frac{87 - 12}{3600}\right)$$

$$= .900y \text{ grams}$$

Step 2: Calculate Reduction in Brake Horsepower-Hour

x = nominal maximum engine horsepower

$$\text{LAF Subcycle} = \frac{\text{Total Subcycle}}{\text{Horsepower-Hour}} = .95x\left(\frac{87}{3600}\right) + .50x\left(\frac{316 - 87}{3600}\right)$$

$$= .0548x \text{ Horsepower-Hour}$$

Substituting 12 seconds of non-WOT, 50% nominal torque for 12 seconds of WOT-equivalent, 95% torgue:

$$\text{New Brake Horsepower-Hour} = .95x\left(\frac{87 - 12}{3600}\right) + .50x\left(\frac{316 - 87 + 12}{3600}\right)$$

$$= 0.533x \text{ Horsepower-Hour}$$

Step 3: Calculate Changes in Subcycle Brake Specific Emissions

$$\text{LAF Subcycle Brake Specific Emissions} = \frac{1.030y}{.0548x} \text{ grams per horsepower-hour}$$

$$= 18.80\,\frac{y}{x}$$

Exhibit A-1 (cont'd)

$$\text{New Emission Rate} = \frac{.900y}{.0533x} \text{ grams per horsepower-hour}$$

$$= 16.89 \frac{y}{x}$$

$$\text{\% Difference} = \frac{16.89 - 18.80}{18.80} \times 100\% = -10.2\%$$

Step 4: Calculate Composite Test Cycle Emission Effects

From Table A-8, LA Freeway BSCO emissions contribute, on average, from 43.2 percent to 68.9 percent of the total composite cycle BSCO emissions for the largest to highest CO-emitting engines, respectively.

Therefore, a 10.2 percent reduction in LA Freeway subcycle emissions will result in an approximate 4.4 percent to 7.0 percent reduction in composite cycle BSCO.

our assumed 90 percent, and in a linear fashion as opposed to our assumed step change. However, it is reasonable to assume that demanding proportionally less power across the subcycle will proportionally decrease the amount of time the power valve is operating, and hence, change the power valve dependent emissions. This likely explains most of the observations in Reference 17. We consider this a reasonable means of estimating the emission effects of decreasing the time spent at power enrichment in the subcycle.)

The regression equations from Reference 17 are presented in Exhibit A-2; calculated changes in composite emissions are also calculated. Note that they are then recorrected for the relative contributions of the LAF subcycle, i.e., the equations assume a percentage decrease in brake-horsepower-hour across the entire composite cycle, whereas we are concerned with the net effect of reallocating a limited number of points in the LAF subcycle alone. (Note that Reference 17 concluded that sensitivity emission trends were identical for each subcycle.) These regression equations, based upon emission data collected from three heavy-duty gasoline (HDG) engines, indicate that one can expect negligible changes in BSHC, less then 4 percent decrease in BSCO, and less than 2 percent increase in BSNOx by decreasing the power valve operation to an extent equivalent to reallocating the 12 misallocated points in the LAF subcycle.

The observed trends in BSCO and BSNOx are consistent with theory. Operation at torques below the power valve generally occurs at marginally rich and at essentially constant A/F ratios. (We assumed earlier that brake specific emissions within this constant air/fuel (A/F) range were essentially constant.) Operation above the power valve increases fuel flow; less oxygen available for complete combustion is the reason CO emissions (partially burned fuel) increase. The additional fuel cools combustion somewhat, leading to observed reductions in BSNOx emissions at WOT conditions.

In summary, EPA concurs that there is somewhat more high speed and load in the LAF subcycle than the CAPE-21 data warrants. Both theoretical analyses and an analysis based upon actual HDG emission data indicate that the emission effects of these additional points are probably minimal (less than 5 percent). Given that the baseline standards were developed with the present cycle (i.e., any inherent biases in the procedure are carried through into the emission standards), and given that the emission effects of this small additional high power operation are minimal anyway, EPA sees no reason whatsoever to characterize the LAF subcycle as unrepresentative based upon the additional high-power operation.

Exhibit A-2: Use of Regression Equations for Three HDG Engines to Predict Changes in Composite Emission Levels as a Function of Changes in LAF BHP-hr

Step 1: Calculate Change in BS Emissions, Given Change in BHP-hr of -2.7%

BSHC* = -.0062 (-2.7) + 2.812 = 2.829 (+.6%)
BSHC = -.004 (-2.7) + 4.837 = 4.848 (+.2%)
BSHC = .0028 (-2.7) + 10.07 = 10.06 (-0.1%)

BSCO = .978 (-2.7) + 49.5 = 46.86 (-5.3%)
BSCO = 1.895 (-2.7) + 79.4 = 74.28 (-6.4%)
BSCO = 2.97 (-2.7) + 144.8 = 136.9 (-5.5%)

BSNOx = -.174 (-2.7) + 13.8 = 14.27 (+3.4%)
BSNOx = -.138 (-2.7) + 6.2 = 6.573 (+6.0%)
BSNOx = -.310 (-2.7) + 11.9 = 12.74 (+7.0%)

Step 2: Correcting for % Contribution of LAF Subcycle to Total Cycle

	Effective Contribution	Corrected % Change to Total Cycle
BSHC	25.8%**	negligible
BSCO	57.4%**	-3.7 to -3.0%
BSNOx	25.0%***	+1.0 to +2.0%

* Expressed in grams/KW-hour.
** Average, all engines from Tables A-5 and A-8.
*** Assumed.

5.3.2 L -- The LAF engine cycle rpm standard deviation was 22.9, while the weighted average of the individual truck standard deviation was 17.2. "Thus, it appears that the cycle variation was excessive."

5.3.2 E -- A.D. Little's assertion that the standard deviation of LAF rpm indicates that excessive variation is present, is judged by EPA to be explainable and inconsequential. Firstly, as indicated in Figure A-2, the actual truck mean rpm's vary so widely that we cannot see how small differences in standard deviations can be meaningful in a practical engineering sense in the first place. Secondly, A.D. Little again neglected the differential operating times of trucks, i.e., their time-weightings. Finally, referring to Figure A-11, we infer that an increased standard deviation of the LAF subcycle rpms relative to that of the input data is explainable by the above-mentioned extra time spent at higher speeds. As also discussed above, the emission impact is minimal.

5.3.3 L -- The correlation of percent power cycle percent rpm for the engine cycles indicated that both the LAF and NYNF compared favorably with the CAPE-21 data, while the LA non-Freeway is "definitely aberrant."

5.3.3 E -- A.D. Little pointed out that the correlation coefficient of percent power with percent rpm for the LANF engine subcycle numerically lies at the low extreme of the distribution of individual truck correlation coefficients (i.e., the subcycle value is less than all but one of the truck's values.) From this, A.D. Little deemed the LANF subcycle "aberrant."

EPA notes that each candidate subcycle was subjected to three discreet evaluation criteria as compared to the input data: 1) the degree of agreement of overall summary statistics (means, medians, percent acceleration, etc.) for both rpm and power, 2) the degree of agreement of the rpm and power distribution functions, as determined by the K-S test, and 3) the degree of agreement of the statistical parameter density plots, as determined by engineering judgment. The final LANF subcycle met the above criteria not only satisfactorily but also better than all other candidate subcycles. The correlation coefficient was not used for subcycle screening purposes; the fact that the coefficient for the selected subcycle lies at the extreme end of the input distribution does not nullify the agreement of all other subcycle parameters with the CAPE-21 input. EPA can only speculate as to the practical engineering significance of the correlation coefficient. The correlation coefficients for the individual trucks are evenly distributed within their ranges of variation, although the ranges do differ apparently with freeway or non-freeway operation. A.D. Little's arguments infer that the LANF, as measured by the correlation coefficient, is too similar to freeway operation, although this is not borne out when all other statistical parameters are reviewed.

In summary, EPA agrees with A.D. Little's observation that the LANF correlation coefficient does not represent an average value of the individual truck coefficients. EPA doubts, however, that this discrepancy constitutes any practical emissions significance, especially given the subcycle's strong agreement with the input data as measured by the other statistical parameters.

<u>5.3.4 L</u> -- Again using a "t-test" and a 95 percent confidence level, 5 out of 48 gasoline engine cycle parameters were non-representative.

<u>5.3.4 E</u> -- A.D. Little again used t-test on distinctly non-normal populations (see Figures A-2, A-5, A-6, and A-7), but provided no valid justification for its use. Application of the central limit theorem is incorrect for samples which are not made up of means. They also erred by using individual truck data instead of making allowances for the actual truck-hours included in the data base. Ignoring these mistakes, however, EPA notes that A.D. Little concluded that LAF rpm mean, median, and standard deviation (discussed and discounted above), LAF power percent acceleration, and LANF power percent motoring were deviant. For each engine subcycle (NYNF, LANF, and LAF), there are two specified operational parameters, rpm and torque/power, each with 8 discreet statistical parameters (mean, median, standard deviation, percent acceleration, percent deceleration, percent motoring, percent cruise, and percent idle.) In short, there are 48 (three subcycles multiplied by two operational parameters multiplied by eight statistical parameters) total parameters to be evaluated. In short, 5 of 48 parameters failed A.D. Little's test. Conversely, 43 of 48, or 90 percent, of the engine cycle parameters were representative of the individual truck data at a 95 percent confidence level, as determined by A.D. Little. Despite 90 percent agreement at a 95 percent confidence level using their own tests, and with no data nor even an educated judgment as to the potential emissions impacts of any of the remaining minor differences in summary percentages/statistics, A.D. Little reached a sweeping, all-inclusive judgment that the engine cycles were unrepresentative. EPA regards this as unreasonably and inappropriately strict.