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TECHNICAL REPORT

Technical Feasibility of the Proposed 1982-1983 High Altitude Standards for Light Duty Vehicles and Light Duty Trucks

by

Robert I. Bruetsch
John J. McFadden
William M. Pidgeon

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Control Technology Assessment and Characterization Branch
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
Office of Air, Noise and Radiation
U.S. Environmental Protection Agency
2565 Plymouth Road
Ann Arbor, Michigan 48105

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Technical Feasibility of the 1982-1983 High Altitude Standards

I. INTRODUCTION

Proposed high altitude standards for the 1982 and 1983 model years (MY) were published on January 24, 1980 [20 at 5988-6009]*. These standards are for light duty vehicles (LDVs) and light duty trucks (LDTs). This document presents an evaluation of the technical feasibility of the proposed high altitude standards (herein referred to as the "standards"), which are listed in Table I-1.

TABLE I-1

Proposed High Altitude Standards for Light Duty Vehicles and Light Duty Trucks*

Year	Vehicle Type	HC	CO	NOx
		g/mi		
1982	Light Duty Vehicles	0.57	7.8**	1.0***
1983	Light Duty Vehicles	0.57	7.8	1.0
1982	Light Duty Trucks	2.0	26	2.3
1983	Light Duty Trucks	1.0	14	2.3****

* A high altitude particulate standard has not been established for the 1982-1983 model years [35 at 14501].

** The high altitude CO standard for engines which have been granted a CO waiver for the 1982 Model Year (MY) is 11 g/mi. [26]

*** The 1982 MY NOx standard for American Motors is 2.0 g/mi [24 at 5990].

**** The 1983 low altitude NOx standard has not yet been determined. This analysis was done for 2.3 g/mi NOx. [26] [24 at 5990]

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* The reference notation [A at B] is used throughout this document. This notation means that the referenced information is found in reference A (from the references section of this document) at page(s) B.

Several vehicle manufacturers have received CO waivers for some of their light duty vehicles in the 1982 model year. A complete list of those manufacturers and engines is presented in Table I-2. Vehicles with these engines must meet a 7.0 CO standard at low altitude [34 at 40030].

Table I-2

Engines with CO Waivers for the 1982 Model Year

American Motors	258 CID.
Chrysler	1.7L 3.7L 5.2L-4V
General Motors	2.8L/173 CID -2V 3.8L/231 CID -2V
Jaguar-Rover-Triumph	215 CID 326 CID
Toyota	88.6 CID

The technical feasibility of the standards was evaluated for the manufacturers and vehicle types listed in Table I-3.

TABLE I-3

Manufacturers and Vehicle Types Assessed

Manufacturer	Light Duty Vehicle	Light Duty Truck
American Motors	Yes	Yes
Chrysler	Yes	Yes
Ford	Yes	Yes
General Motors	Yes	Yes
Honda	Yes	No
International Harvester	No	Yes
Jaguar-Rover-Triumph	Yes	No
Nissan	Yes	Yes
Peugeot	Yes	No
Toyota	Yes	Yes
Volkswagen	Yes	Diesel only

The manufacturers listed in Table I-3 include all of those who commented on the proposed regulations.

Many of the manufacturers submitted little or no high altitude test data for the emission control systems they plan to use in the 1982 and 1983 model years. Due to the scarcity of high altitude test data, this evaluation is not based on as broad a data base as EPA would prefer to use in its technical assessments.

II. CONCLUSIONS

It is the judgement of the EPA technical staff that the proposed high altitude standards for the 1982-1983 model years are technically feasible. This judgement is based on the analyses made for the manufacturers listed in Table I-2 and the assumption that the technical ability of these manufacturers is representative of the automotive industry.

The primary reason for emissions problems at high altitude is the fact that as altitude increases, the air density decreases. This causes the air/fuel ratio of non-altitude compensated fuel metering systems to enrich as altitude increases. Attendant with richer mixtures are increases in HC and CO emissions. Therefore, in order to prevent or limit increases in HC and CO emissions with increases in altitude, the air/fuel ratio enrichment has to be limited, and/or the emission control aftertreatment system has to be modified to increase its effectiveness in converting the increased engine-out emissions. The methods of achieving those objectives vary with the type of emission control system.

For open-loop systems, the following options are available:

1. Recalibrated carburetors for vehicles sold at high altitudes.

2. Carburetors equipped with an aneroid which allows the carburetor to automatically recalibrate at high altitude to limit air/fuel ratio enrichment.

Closed-loop systems are inherently self compensating when they are operating in the closed-loop mode, as long as the fuel metering system is operating within its range of authority. Sometimes, some of these systems are in the open-loop mode. For example, open-loop operation is not uncommon during cold start and wide open throttle (WOT) for some systems. Other open-loop modes are possible. In these open-loop modes, the air/fuel ratio will enrichen with altitude unless there are control systems incorporated to limit the enrichment. Two strategies exist here. One is to recalibrate the open-loop modes for vehicles to be sold at high altitude. The second is to have the open-loop calibrations automatically compensated for altitude with a control system that senses ambient and/or manifold air pressure. Adaptive memory such as GM's "keep-alive" memory is another technique to correct the open-loop calibrations for the altitude at which the vehicle is being operated.

Another strategy to reduce HC and CO emissions at all altitudes would be to maintain a stoichiometric air/fuel ratio at WOT. In most cases, the air/fuel ratio is purposely enrichened to increase power. A review of combustion engines textbooks [37 at 343; 38 at 69; 39 at 492; 40 at 402-403] showed that the typical shape of the brake mean effective pressure (BMEP) versus air/fuel ratio curve is relatively flat between stoichiometric and the air/fuel ratio that yields maximum BMEP. BMEP is directly proportional to power. According to these texts, the increase in power (BMEP) caused by enrichening the air/fuel ratio from stoichiometric to a best power air/fuel ratio ranges from 0% to approximately 5%.

The data in Table II-1, which were developed by the Southwest Research Institute for an EPA contract [41 at 46], fall within the range mentioned above.

Table II-1

EFFECT OF FUEL TO AIR RATIO AT WOT

Calc. Air/Fuel	Power, kW	% BL WOT	Concentration as Measured HC, ppm	CO, pct	CNO_x, ppm	SFC, kg/kW-hr
12.0	72.7	102	2224	6.96	239	0.35
12.8	71.2[a]	100	1776	4.75	647	0.33
13.2	70.6	99	1552	3.36	1041	0.32
13.8	70.1	99	1184	1.87	1624	0.30
14.6	68.4	96	96	0.31	2147	0.30
15.0	65.8	93	1	0.03	2305	0.30
15.8	62.8[b]	88	1	0.02	2114	0.31
16.8	57.6	81	1	0.02	1373	0.32
17.8	50.1	71	1	0.02	658	0.35

[a]Baseline maximum power is approximately 71 kW.

[b]90 percent of baseline maximum power is approximately 64 kW.

NOTE: 14° BTDC at 2000 rpm, with thermal reactor, no air injection; CNOx is NOx corrected for humidity.

These data show that the power loss was only 4% from the baseline WOT air/fuel ratio of 12.8:1, to the stoichiometric ratio of 14.6:1, but the HC concentration dropped from 1776 ppm to 96 ppm, CO dropped from 4.75% to 0.31%, and fuel consumption also decreased.

For the analysis that follows, the EPA staff has concentrated on control approaches that control engine air/fuel ratio. The other control option, that of increasing the effectiveness of the aftertreatment system, is not discussed in any great detail. It is an option, however. For example, increased catalyst size and/or increased air pump delivery rate (larger pump or higher pump speed) could reduce any altitude-caused increase in HC and CO emissions to acceptable levels.

III. METHODOLOGY

The EPA technical staff made pass/fail judgements on the manufacturers' technical ability to comply with the standards. The following four methods were used in making the pass/fail judgements.

1. The first method used high altitude data for emission control systems which the EPA technical staff predicted would be used by the manufacturers for the 1982-1983 model years. These data were averaged for each engine group. The averages were then multiplied by deterioration factors taken from 1981 certification data for that manufacturer. The calculated results were then compared to the standards.

2. The second method utilized 1981 certification test data from emission data vehicles and deterioration factors (dfs) from 1981 certification durability vehicles. Factors were developed to reflect the change in emissions based on tests at high and low altitudes. These three data sets were multiplied to calculate the predicted high altitude emissions at 50,000 miles. These predicted levels were then compared to the standards.

3. The third method is the same as method 2, but instead of emission data vehicle results, 4,000 mile extrapolated emission results from the 1981 certification durability vehicles were substituted. Therefore, the dfs and 4000 mile emissions were from the same vehicles.

4. Technical knowledge of the emission control system's ability to compensate for altitude was used for situations where data were unavailable or to specifically address issues raised by the particular manufacturer being evaluated.

Before using any of the four methods it was necessary for EPA to predict the engine displacements and emission control technology to be used by each manufacturer. In most cases these judgements were based on information from four sources; a) 1981 certification data, b) CO waiver applications, c) testimony from the 1982-1983 high altitude hearings, comments on the 1982-1983 high altitude NPRM, and d) written responses to questions from the hearing panel. Of these four sources, only the 1981 certification data were not yet publicly available. While certification data were considered in this analysis, data which were unavailable from the other sources have been removed from this text. In such cases, the engine displacement was replaced by a letter designation and the emission control system description was replaced by a number.

Where the manufacturer has historically grouped more than one engine displacement in an engine family, or where the EPA technical staff judged that several engine displacements were equipped with similar emission control systems, these engines were evaluated as a group in order to expedite the analysis. Several engine displacements were available with more than one emission control system. The prime concern was to evaluate whether the manufacturer had the technology for each engine group to comply with the standards. It was not an objective of this analysis to determine whether every combination of engine displacement and emission control system, which the manufacturer had available, could comply with the standards. Therefore, in most cases, only one such combination was evaluated.

In methods 1 thru 3, four different data sets were used. The 1981 certification dfs comprised one of the data sets. The dfs were taken from the EPA Certification Status Report of July 11, 1980 and averaged for each engine group. Deterioration factors were only calculated for vehicles with at least three valid tests and a 15,000 mile test. Vehicles which were line crossing* were not included in the average.

* A durability vehicle is considered to be line crossing when the results from one or more valid tests are above the 1982-1983 model year low altitude standards, and either the extrapolated 4K or extrapolated 50K results are also above the same standards.

Because manufacturers have historically generated dfs for more engine families than they actually market, a second set of dfs was also used. In many cases, a manufacturer will actually market only those engine families whose durability vehicles achieved the lowest deterioration factors. In order to reflect these practices, EPA selected the durability data within the engine group which had the best combination of results when considered with the altitude factors and the 4,000 mile data. The best combination results would give the engine group the highest probability of passing the standards. These deterioration factors are referred to as the "lowest dfs". It should be noted that the dfs from the single durability vehicle with the best combination results was chosen, and not the lowest dfs from among all the individual vehicles within the engine group. The selected vehicle's dfs were then used in the calculations.

The second data set used in methods 1, 2 and 3 were low mileage test results. In method 1, low mileage high altitude test results were used along with certification dfs in order to predict 50,000 mile emissions at high altitude. Due to the scarcity of high altitude test data, method 1 was infrequently used.

In method 2, the low mileage test results were the 4,000 mile certification results from 1981 emission data vehicles which had been assigned a certification disposition of passing. The cutoff date for this data was July 15, 1980 for light duty vehicles, and July 23, 1980 for light duty trucks. These data were then averaged for each engine group.

Because the 1981 Federal CO standard for light duty vehicles is more stringent than the California standard, where possible, only emission data vehicles calibrated for sale in 49-states or 50-states were included in 4,000 test averages. For light duty trucks, the opposite is true. The California standards are more stringent. In this case California trucks and 50-state trucks were used in the 4,000 mile test averages.

Durability vehicles were selected by emission control system only. Sales location was not a critereon in their selection. All durability vehicles with at least three valid tests, a 15,000 mile test, and which were not considered to be line crossing, were used for the df averages and the extrapolated 4,000 mile results.

The third data set was used when 4,000 mile emission data vehicle test results with a certification disposition of passing were not available. Instead, extrapolated 4,000 mile results from the durability vehicles within the EPA designated engine group were averaged and used. Only those vehicles which met the criteria to be included in the df average were included in the 4,000 mile average. These data were gathered on July 17, 1980, and used in method 3.

The fourth set of data used in methods 2 and 3 were factors reflecting the change in emissions for a vehicle tested at high and low altitudes. Development of these factors will be discussed in a later section.

As mentioned, method 4 was used when the data required for methods 1 thru 3 were unavailable, or in order to address specific issues raised by a particular manufacturer.

IV. HIGH ALTITUDE TO LOW ALTITUDE EMISSIONS FACTORS

Multiplicative factors have been developed to reflect the difference in emissions for vehicles tested at high and low altitude. These factors were used in methods 2 and 3 to estimate or predict the emissions of 1981 certification emission data vehicles at high altitude, based on their low altitude test results.

Factors were developed for the following generic emission control systems:

1. Pulse or aspirator type air injection systems (PAIR), oxidation catalysts (OC), and exhaust gas recirculation (EGR) with aneroid carburetors.

2. Air injection systems using air pumps (AIR),OC, and EGR.

3. Feedback carburetion (FBC), 3-way catalysts (3W), AIR, OC, and EGR.

4. Closed-loop electronic fuel injection (CLEFI), 3W and EGR.

All the factors in this section were developed from light duty vehicles, but were used to calculate the predicted altitude emissions of light duty trucks in addition to light duty vehicles. Concern was expressed by the manufacturers that the power-to-weight ratios for LDTs were lower than for LDVs and inferred that high altitude emission standards would be especially burdensome for LDT manufacturers for this reason [4 at 95-96 and 6 at 7].

The manufacturers also stated that higher axle ratios would be required on low power-to-weight ratio light duty vehicles in order to comply with the proposed high altitude standards [42 at 1&2 and 6 at 3 & Attachment II]. However, the manufacturers did not provide data or analyses to support these statements. In fact, the data listed in Table Ford-2 (see section 5) indicate that the higher the axle ratios, the higher the percent increase in emissions. However, it should be noted that there are only a limited amount of data and the comparison involves different vehicles with different axle ratios, rather than the same vehicles with different axle ratios.

Because of manufacturers' statements inferring that low power-to-weight ratios could be compensated for with higher axle ratios, the technical staff calculated power-to-weight ratios for the LDVs from which the factors were derived and for the LDTs to which the factors were applied. Rear axle ratios were also compared. Although the technical staff kept track of the power-to-weight ratios and axle ratios, the altitude factors were not adjusted or modified as a result of the comparisons.

In most cases, the power-to-weight ratios for LDTs were lower than for the LDVs from which the factors were derived (reference vehicles), but the axle ratios were always higher for the LDTs which had lower power-to-weight ratios than the reference vehicles. The power-to-weight ratios were calculated by dividing the rated horsepower by the equivalent test weight.

The power-to-weight ratios and rear axle ratios for the LDTs and reference vehicles were compared on a percent difference basis (i.e. $\% \text{ Difference} = \left(\frac{\text{LDT parameter}}{\text{Reference Vehicle Parameter}} - 1\right) \times 100$. A negative value means that value of the parameter for the LDT was lower than the reference vehicles' and a positive value means that the value of the parameter for the LDT was higher. Where there was a larger percent difference in power-to-weight ratios than in axle ratios (e.g. -20% power-to-weight and +10% axle ratio), the predicted emission results were checked for their proximity to the emission standards. No cases were found where a pass/fail determination was made for an engine/vehicle combination which had a higher percent difference in power-to-weight ratio than in axle ratio and also had predicted emission levels which were close to the proposed standards. If the power-to-weight ratio was higher for the LDT than for the reference vehicle, the factors were considered appropriate.

Although the power-to-weight ratios for the light duty trucks were often times lower than for the reference vehicles, this may not be true of the vehicle fleet.for 1982 and 1983. Projected 1980 sales data indicate that the average engine displacement in cubic inches (CID) will be 210.5 for LDVs and 284.9 for LDTs. The average inertia weight will be 3283 pounds for LDVs and 4194 pounds for LDTs [36 at 5 and 57]. The engine displacemnt to inertia weight ratio for LDTs is projected to be 0.0679 in^3/lb, whereas for LDVs it is projected to be only 0.0641 in^3/lb. In other words, the displacement-to-weight ratio is projected to be 6 percent higher for LDTs than for LDVs.

PAIR/OC/EGR Altitude Factors

The altitude factors for the PAIR/OC/EGR emission control system with an altitude compensated carburetor were developed from data submitted by Nissan [8 at 3] and listed in Table IV-1.

Table IV-1

PAIR/OC/EGR Altitude Factors

VIN	Altitude (ft)	HC	CO	NOx
		g/mi		
A	0	0.34	4.1	0.51
	5249	0.34	5.7	1.3
	Factors*	1.00	1.39	2.55
B	0	0.30	2.4	0.98
	5249	0.36	5.1	1.59
	Factors*	1.20	2.13	1.62
	Avg. Factors as calculated	1.10	1.76	2.09
	Avg. Factors* as used for Nissan	1.10	1.76	Not used**
	Factors* as used for manufacturers other than Nissan	1.70	1.80	Not used**

* Factors are dimensionless.

** See test.

The average NOx factor of 2.09 is extraordinarily high in view of the fact that there is widespread agreement that NOx usually decreases as altitude increases. In reference to the data included in Table IV-1, Nissan stated,

> In the case of our "Oxidation Catalyst + Heavy EGR system... the frequency of WOT operation where EGR does not work is increased because of insufficient engine power [8 at 3].

Nissan further explained that the EGR control system would be revised "to control EGR near WOT acceleration [8 at 3]."

These factors were developed from engines which utilize "heavy EGR" for NOx control, which Nissan admits, needs to be better controlled under high altitude operating conditions.

Because it is technically feasible to control EGR near WOT, and because the other manufacturers assessed in this analysis did not express a concern about NOx control at high altitude, the NOx factor derived from the Nissan data was not used in assessing the technical capability of other manufacturers. Since the technical staff was not aware of additional data for a PAIR/OC/EGR control system with an altitude compensated carburetor, a factor was not used for NOx. Instead, a maximum tolerable factor was calculated by dividing the NOx standard by the product of the low mileage emissions times the df. If the maximum calculated factor was greater than 1.0, then NOx emissions were considered to pass the standard.

The factors for vehicles with an air pump and an oxidation catalyst were 1.65 for HC and 1.73 for CO. The EPA technical staff was skeptical of using altitude factors showing significantly better altitude compensation for a PAIR system than for an air pump system. For this reason, the HC factor for the PAIR/OC/EGR system was changed from the calculated value of 1.10 to 1.70 to make it more conservative than the AIR/OC/EGR system's HC factor of 1.65. The CO factor was rounded up from 1.76 to 1.80. The 1.70 HC and 1.80 CO factors were used for manufacturers other than Nissan. Since these factors were developed from Nissan data, the calculated values, 1.10 for HC and 1.76 for CO, were used as calculated for Nissan.

These factors were considered appropriate even for engines without "heavy EGR". The rate of EGR flow should not influence the carburetor's ability (to meter fuel) to compensate for altitude nor the PAIR system's ability to supply sufficient oxygen to the exhaust stream to maintain catalyst efficiency.

AIR/OC/EGR Altitude Factors

The factors for the AIR/OC/EGR emission control system with an altitude compensated carburetor were developed from light duty vehicle data submitted by Ford [6 at Attachment 3] and listed in Table IV-2.

TABLE IV-2

AIR/OC/EGR Altitude Factors

VIN	Location	HC	CO	NOx	#Tests
		------g/mi-------			
#4	Dearborn	0.23	1.1	0.87	1
	Denver	0.38	1.9	0.90	2
	Factors* as calculated and used	1.65	1.73	1.03	

* Factors are dimensionless.

The factors were used as calculated for both light duty vehicles (LDVs) and light duty trucks (LDTs). The power-to-weight ratio for vehicle #4 was 0.0375 hp/lb and the axle ratio was 2.26.

FBC/AIR/3W/OC/EGR Altitude Factors

The factors for the FBC/AIR/3W/OC/EGR emission control system were developed from data submitted from Chrysler [7 at Appendix C] and Ford [6 at Attachment III]. These data are listed in Table IV-3. The Chrysler vehicles tested in Denver had minor adjustments for high altitude operation. The Ford vehicle did not have adjustments.

Table IV-3

FBC/AIR/3W/OC/EGR Altitude Factors

Mfr	VID	Location	HC	CO	NOx	#Tests
			----------	g/mi	----------	
Ford	#5	Dearborn	0.17	0.9	1.64	1
		Denver	0.19	2.3	1.59	2
Factors* as calculated and used for Ford vehicles			1.12	2.56	0.97	
Chrysler	315	Detroit	0.13	1.35	0.80	--
		Denver	0.16	2.21	1.14	--
	078	Detroit	0.10	0.65	1.25	--
		Denver	0.19	3.13	1.28	--
	307	Detroit	0.22	1.62	0.77	--
		Denver	0.40	2.28	0.89	--
	343	Detroit	0.30	1.85	0.82	1
		Denver	0.38	5.06	0.90	2
Chrysler factors* as calculated by EPA			1.55	2.65	1.18	
Factors* as used for Chrysler vehicles			1.55	2.65	1.00	
Averaged factors* used for manufacturers other than Ford and Chrysler			1.47	2.63	1.00	

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* Factors are dimensionless.

Because of differences in the capability of each manufacturer's feedback control system to compensate for altitude, the altitude factor developed from Ford data was used for assessing Ford's engines and likewise for Chrysler. The Ford and Chrysler data were averaged for assessing the technical capability of manufacturers other than Chrysler and Ford. These factors are listed in Table IV-3.

The technical staff did not use the NOx factor of 1.18, but instead used a factor of 1.0. Chrysler stated the following in relation to NOx:

> NOx is not specifically addressed in this NPRM because NOx emissions decrease with altitude as the engine mixture richens. Therefore, NOx standards set at low altitude provide a certain fortuitous degree of extra NOx control at high altitude. If, as the EPA proposes, present air-fuel systems are re-calibrated or controlled to more stoichiometric air-fuel ratios (i.e. leaner), NOx emissions may actually increase [7 at p.7].

Although the technical staff agrees that leaner mixtures sometimes can lead to increased engine-out NOx emissions, the object with a closed-loop three-way catalyst system is to maintain stoichiometry. The problem is in keeping the system from going too rich rather than too lean. The CO factor of 2.65 indicates that this system is enrichening with increases in altitude. EPA feels that the increase in NOx emissions is probably due to EGR calibration and control. Like Nissan, Chrysler may have to revise their EGR control system for high altitude. Neither Chrysler nor Nissan indicated it would be a problem, and other manufacturers have not made an issue of NOx control at high altitude. EPA therefore used an NOx factor of 1.0 for control systems with FBC/AIR/3W/OC/EGR, except for Ford vehicles which used the 0.97 NOx factor. The 0.97 NOx factor was calculated from Ford data.

CLEFI/3W/EGR Altitude Factors

The ratios for this emission control system were developed from data submitted by Nissan [8 at p.3] and listed in Table IV-4. The EFI system included an altitude compensation device.

Table IV-4

CLEFI/3W/EGR Altitude Factors

VIN	Altitude (ft)	HC	CO	NOx
		g/mi		
C	0	0.31	2.1	0.47
	5249	0.52	5.4	0.35
	Factors* as calculated	1.68	2.57	0.74

*Factors are dimensionless.

The Nissan electronic fuel injection system is similar to the Bosch L-jetronic system. Bosch stated that "the controlled range is designed such that no error exists for altitudes up to 2,500 meters [8,200 ft] [2 at Annex 5, p.5]." This factor was used as calculated.

V. INDIVIDUAL MANUFACTURER'S DISCUSSIONS

A. Gasoline-Fueled Vehicles

American Motors Corporation (AMC)

Light Duty Vehicles

EPA assumed that the following engines will be marketed in 1982 and 1983 based on information provided in AMC's CO waiver request and 1981 certification information.

1. 151 CID FBC/AIR/3W/OC/EGR
2. 258 CID - (1982) Control System 1*
   - (1983) FBC/AIR/3W/OC/EGR

Pass/Fail Analysis of the 151 CID Engine

Representatives of AMC testified at the high altitude hearings of March 5, 1980 that:

> Our four cylinder technology we receive from General Motors. We buy as a total package, and we have a California package and a nationwide package [4 at 243].

AMC also stated that the control system used on this engine includes a feedback carburetor, air pump, three-way catalyst, oxidation catalyst and EGR [4 at 244 and 21 at 7130]. GM submitted data from development vehicles tested at high altitude (see 1.6L engine data in Table GM-1 in the GM section of this report). Two 151 CID engine vehicles were among those tested at low mileage. A method 1 analysis was performed on these vehicles using dfs from two 1981 GM certification durability vehicles. The lowest dfs case exhibits predicted results of 0.57/6.6/0.8 (see Table GM-1), which are below the 1982 and 1983 high altitude standards. Using the average dfs from three 1981 GM certification durability vehicles and the average low mileage results from two 151 CID GM vehicles tested at high altitude, the predicted results indicate the 151 CID engine will fail.

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* Not yet publicly released.

Although AMC did not submit high altitude data for this engine, the data submitted by GM are judged to be indicative of the emission control system's ability to compensate for altitude. As explained in the factors section, the closed-loop three-way catalyst system is designed to maintain stoichiometry and thereby compensate for increases in altitude. The CO factor from the Chrysler and Ford data is 2.65, and it is judged that the GM system is at least as efficient for altitude compensation if not more so. Based on the predicted results using the lowest dfs, EPA concludes that AMC has the technical capability to meet the standards with the 151 CID engine.

Pass/Fail Analysis of the AMC 258 CID Engine

Based on 1981 certification information, AMC is expected to use emission control system 1* for the 1981 and 1982 model years. This engine has been granted waivers to 7.0 gpm CO and to 2.0 gpm NOx for 1981 and 1982 MYs [23 at 53377] and [24 at 5990]. This converts to high altitude standards as follows:

	1982	1983
HC	0.57 gpm	0.57 gpm
CO	11 gpm	7.8 gpm
NOx	2.0 gpm	1.0 gpm

Information from AMC's CO waiver request indicates that they will be using a FBC/AIR/3W/OC/EGR control system in order to comply with the 1983 MY low altitude CO standard (3.4 g/mi).

Emission control system 1 was not evaluated because altitude factors were not available. The FBC/AIR/3W/OC/EGR emission control system also could not be evaluated because AMC dfs and 4K data were not available.

* Not yet publicly released.

The following statement is excerpted from the AMC submission [25 at 8]:

> Beginning with the 1980 MY, the manufacturer is required to submit data to ARB [California Air Resources Board] which show the tailpipe air/fuel ratio is leaner than stoichiometric to altitudes up to 6000 feet. AM is presently using the analytical method described in this advisory circular [Advisory Correspondence #78-2].

The technical staff's knowledge of AMC's emission control systems leads us to believe that the 258 CID engine will be able to comply with 1982 and 1983 high altitude standards listed at the beginning of this pass/fail analysis. The prior quote from AMC and their statement that "AM does not dispute the basic feasibility of the proposed standards [25 at 4]" lends support to this belief. But in the final analysis, the technical staff concludes that it does not have enough information to support a judgement on the 258 CID engine's ability to comply with the applicable standards.

American Motors

Light Duty Trucks

EPA assumes that the following engines will be marketed in 1982 and 1983 based on 1981 certification information.

Engine Displacement	Emission Control System
1. A cu. in.	1
2. B cu. in.	2
3. C cu. in.	2
4. D cu. in.	2

Pass/Fail Analysis of the AMC A LDT Engine

AMC did not submit high altitude data for this light duty truck engine. No emission data vehicle or durability vehicle data were available for this analysis either. Therefore, a method 4 analysis was used for this engine.

The A engine is equipped with emission control system 1. Although the emission control system is not exactly the same as for the light duty vehicle version of this engine, the technical staff feels that the LDT's ability to compensate for altitude should be almost as effective as the LDVs. Data from the LDV version of this engine at high altitude show that one vehicle with the A engine is projected to pass the LDV standards at 50,000 miles. The light duty truck standards are considerably less stringent than the light duty vehicle standards met by this vehicle with a similar control system. Because the data indicate that this system can compensate for altitude, EPA concludes that AMC has the technical capability to meet the LDT standards with the A engine.

Table AMC-1

American Motors LDT

DISP.*	Emission Control System*	HP/ETW RATIOS: Ref. Veh. ($X 10^{-2}$)	HP/ETW RATIOS: Cert. 4K Veh's. ($X 10^{-2}$)	HP/ETW RATIOS: LDT to 4K Ref. Veh. (%)	AXLE RATIOS: Ref. Veh. ($X 10^{-2}$)	AXLE RATIOS: Cert. 4K Veh's. ($X 10^{-2}$)	AXLE RATIOS: LDT to 4K Ref. Veh. (%)	Cert. 4K Tests			High to Low Altitude Factors			Cert. dfs	Predicted Results			Pass-Fail						Comments
								HC	CO	NOx	HC	CO	NOx		HC	CO	NOx	1982			1983			
								---g/mi--							-------g/mi-------			HC	CO	NOx	HC	CO	NOx	
B	#2	*	*	+5	*	*	+12	*	*	*	*	*	*		1.14	24.7	1.68	P	P	P	F	F	P	Lowest dfs
															1.26	24.9	1.68	P	P	P	F	F	P	Average dfs (2)
C	#2	*	*	+14	*	*	+21	†	†	†	*	*	*		1.65	10.7	1.75	P	P	P	F	P	P	1980 Cert. Data
D	#2	*	*	-6	*	*	+19	*	*	*	*	*	*		0.99	17.1	1.63	P	P	P	P	F	P	One vehicle

* Not Yet Publicly Released.

† 1980 Certification Data - [22 at Trucks]: 0.967 HC, 7.72 CO, 1.69 NOx.

Pass/Fail Analysis of the AMC B, C, & D LDT Engines

High/low altitude factors were developed for system 2 on a LDV in Section IV. The hp/ETW ratios and the axle ratios were greater for engines B and C than for the reference LDV, as shown in Table AMC-1. For engine D, the hp/ETW ratio was lower than for the reference LDV.

A pass/fail analysis of the B and D CID engines was conducted by use of method 2 since some 1981 certification data were available. The analysis of the C engine also made use of the 1980 certification data. Results are shown in Table AMC-1.

The technical staff concludes that all three engines can comply with the 1982 LDT high altitude standards of 2.0 HC, 26 CO, and 2.3 NOx. The data also show that these engines are not capable of satisfying the more stringent high-altitude standards established for the 1983 model year (1.0 HC, 14 CO, and 2.3 NOx) without recalibration or other advanced emission control system design strategies.

The technical staff concludes that AMC has the technology to comply with the 1982 high altitude LDT standards, but will need to complete additional work to comply with the 1983 standards.

Chrysler

Light-Duty Vehicles

EPA assumed that the following engines would be marketed in 1982 and 1983 based on information provided in Chrysler's CO waiver request.

1. 1.7L FBC/AIR/3W/OC/EGR.
2. 2.2L FBC/AIR/3W/OC/EGR.
3. 2.6L PAIR/OC/EGR.
4. 3.7L AIR/OC/EGR.
5. 5.2L FBC/AIR/3W/OC/EGR.

Pass/Fail Analysis of the Chrysler 1.7L Engine

The emission control system for the 1.7L engine is expected to include FBC/AIR/3W/OC/EGR. Listed in Table Chrysler-1 are the altitude factors for Chrysler's feedback carburetion system and the lowest and average dfs from 1981 certification data for this engine. These data were used in a method 2 analysis. The dfs were taken from three durability vehicles and the 4K data were averaged from four emission data vehicles.

The predicted high altitude emission levels are 0.35, 4.96 and 0.86, using the lowest dfs, for HC, CO, and NOx respectively, and are 0.40, 6.86, and 0.86 using the average dfs. The 1.7L engine should easily pass the 1982-1983 high altitude standards. Since this engine has a CO waiver for the 1982 model year, it only has to meet a CO standard of 11 g/mi rather than 7.8.

Pass/Fail Analysis of the Chrysler 2.2L Engine

This engine was represented by five emission data vehicles and five durability vehicles. Table Chrysler-1 has three different sets of deterioration factors. The first of these represents the deterioration

TABLE CHRYSLER-1

Chrysler LDV

DISP	EMISSION CONTROL SYSTEM	CERT. 4K TESTS*			HIGH TO LOW ALTITUDE FACTORS			CERT dfs*			PREDICTED RESULTS			PASS-FAIL				COMMENTS
		HC	CO	NOx	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx	HC	CO_{11}**	$CO_{7.8}$	NOx	
1.7L	FBC/AIR/3W/OC/EGR				1.55	2.65	1.00				0.35	5.0	0.7	P	P	P	P	Lowest dfs
											0.40	6.7	0.7	P	P	P	P	Avg dfs (3)
2.2L	FBC/AIR/3W/OC/EGR				1.55	2.65	1.00				0.41	5.0	0.6	P	--	P	P	Lowest dfs
											0.58	10.0	0.9	F	--	F	P	Avg dfs (5)
											0.38	6.2	0.6	P	--	P	P	Avg dfs (4)
2.6L	PAIR/OC/EGR				1.70	1.80	1.40***				0.44	5.6	1.0	P	--	P	P	Lowest dfs
											0.37	6.8	1.0	P	--	P	P	Avg dfs (4)
3.7L	#1				*	*	*				0.49	4.7	0.8	P	P	P	P	One vehicle
5.2L-2V	FBC/AIR/3W/OC/EGR				1.55	2.65	1.00				0.22	3.8	0.9	P	--	P	P	Lowest dfs
											0.29	4.3	1.0	P	--	P	P	Avg dfs (5)

* Not Yet Publicly Released.

** Engines with a CO waiver have a "P" or "F" in this column. Engines without a CO waiver have a "--" in this column.

*** Maximum altitude factor which allows vehicle to pass.

factors generated by the best case vehicle for this engine group. The second set of deterioration factors represents an average of five deterioration factors and the third group is an average of four deterioration factors. One of the durability vehicles had dfs of greater than 5.0 for both HC and CO. In the opinion of the technical staff, it is highly improbable that any manufacturer would market an engine family whose deterioration factors are greater than five. Therefore, an analysis was done for average deterioration factors both including and excluding this vehicle.

The results in Table Chrysler-1 indicate that the 2.2L engine is capable of meeting the high altitude standards using the best dfs and the average of 4 dfs, but failed both HC and CO when the average of 5 dfs were used. In the judgement of the EPA technical staff, the 2.2L engine is capable of meeting the high altitude standards.

Pass/Fail Analysis of the Chrysler 2.6L Engine

The Chrysler 2.6L engine's emission control system is expected to include PAIR/OC/EGR. The data base for this engine included five emission data vehicles and seven durability vehicles. Of these seven durability vehicles, only four were used in the average because two line crossed and one had less than 15,000 miles.

According to Chrysler, vehicles not using three-way catalysts will use altitude compensating carburetors [7 at 23]. As discussed in the factors section, the only high and low altitude data for this type of emission control system were submitted by Nissan [8 at 3]. This engine was evaluated using factors of 1.70 and 1.80 for HC and CO respectively. The Nissan data, as explained in the PAIR/OC/EGR factors section, yielded a factor of 2.09 for NOx. The 2.09 NOx factor is not an appropriate factor for use in analyzing the Chrysler engine's ability to meet the 1.0 NOx standard at high altitude. Nissan indicated they were using "heavy EGR" but said

> The frequency of WOT operation where EGR does not work is increased because of insufficient engine power [8 at 2].

Since NOx control is not an issue and additional data were not available, a NOx factor was not used. Instead, calculations were made to evaluate the highest factor which would still allow the engine to comply with the 1.0 NOx standard. As Table Chrysler-1 shows, even with a NOx factor of 1.40, or a 40% increase in NOx at a high altitude, the 2.6L engine is able to comply with the high altitude standards. Therefore, with ratios of 1.70, 1.80, and 1.40 for HC, CO and NOx respectively, the 2.6L engine is capable of complying with the high altitude standards using the lowest dfs or the average dfs.

Pass/Fail Analysis of the Chrysler 3.7L Engine

Based on 1981 certification information, the 3.7L engine is expected to be equipped with an emission control system 1*. This engine was represented by four emission data vehicles and one durability vehicle. Although this engine has a CO waiver for 1982, the results in Table Chrysler-1 indicate that it will easily comply with the 1982-1983 high altitude standards, even for engines without a CO waiver.

Pass/Fail Analysis of the Chrysler 5.2L Engine

The emission control system for the 5.2L engine is expected to include FBC/AIR/3W/OC/EGR. Table Chrysler-1 lists the emission data vehicle results, the altitude factors for this emission control system and the predicted high altitude emissions results of 0.22 HC, 3.8 CO, 0.9 NOx with the lowest dfs and 0.29 HC, 4.3 CO, 1.0 NOx using the average dfs. These data were developed in a method 2 analysis.

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* Not yet publicly released.

To save time only the two barrel carbureted version was assessed for two reasons. First, it does not have a CO waiver for 1982, and therefore has to meet the more stringent CO standard of 7.8 g/mi. Second, we expect it to be produced in higher production volumes than the other two versions.

The predicted results for this engine indicate that it will be able to comply with the 1982-1983 high altitude standards using either the lowest dfs or the average dfs.

Chrysler

Light Duty Truck

Chrysler is expected to market the following engines in 1982-1983 for their light duty trucks. This information is based on 1981 certification data.

	Displacement	Emission Control System
1.	A	1
2.	B	1
3.	C	1

Pass/Fail Analysis of the Chrysler A LDT Engine

This engine was represented by three emission data vehicles and three durability vehicles. The durability data vehicles included B033R, D103 and D104.

The altitude factors used in this method 2 analysis were developed from light duty vehicle data. The rear axle ratio for the LDTs was more than 55% higher than the average rear axle ratio for the reference vehicles. Although the horsepower-to-equivalent test weight ratio is approximately 40% higher for the LDVs than the average hp-to-ETW ratio for the LDTs, it is still considered appropriate to use in light of the higher LDT rear axle ratios.

Using a method 2 analysis, as shown in Table Chrysler-2, the predicted emission levels were 0.8 HC, 6 CO, and 1.1 NOx using the lowest dfs and 0.8 HC, 7 CO and 1.1 NOx using the average dfs. These data indicate that this engine will easily meet the standards when emission control system 1 is used.

TABLE CHRYSLER-2

Chrysler LDT

DISP.*	Emission Control System*	HP/ETW RATIOS: Ref. Veh.* ($X 10^{-2}$)	HP/ETW RATIOS: Cert. 4K Veh's.* ($X 10^{-2}$)	HP/ETW RATIOS: LDT to 4K Ref. Veh. (%)	AXLE RATIOS: Ref. Veh.* ($X 10^{-2}$)	AXLE RATIOS: Cert. 4K Veh's.* ($X 10^{-2}$)	AXLE RATIOS: LDT to 4K Ref. Veh. (%)	Cert. 4K Data* HC CO NOx ---g/mi--	High to Low Altitude Factors* HC CO NOx	Cert. DF's*	Predicted Results HC (g/mi)	Predicted Results CO (g/mi)	Predicted Results NOx (g/mi)	Pass-Fail 1982 HC	Pass-Fail 1982 CO	Pass-Fail 1982 NOx	Pass-Fail 1983 HC	Pass-Fail 1983 CO	Pass-Fail 1983 NOx	Comments
A	1			41			+57				0.8	6	1.1	P	P	P	P	P	P	Lowest dfs
											0.8	7	1.1	P	P	P	P	P	P	Avg dfs (3)
B/C	1			0**			+23%				0.7	10	1.5	P	P	P	P	P	P	Lowest dfs
											0.8	10	1.5	P	P	P	P	P	P	Avg dfs (3)

* Not Yet Publicly Released.

** Inertia weight class was used to calculate the power-to-weight ratio.

Pass/Fail Analysis of the Chrysler B & C LDT Engines

The B and C engines with emission control system 1, were represented by durability vehicles C040, 4010 and C026. The dfs were averaged from all three vehicles, as were the extrapolated 4000 mile emission levels. Because emission data vehicle results were not available, a method 3 analysis was used. Since these engines have historically been certified in the same engine family the data have been averaged for an analysis of both engines.

As Table Chrysler-2 shows, in this case, the power-to-weight ratios of the LDTs were the same as for the LDVs from which the altitude factors for emission control system 1 were developed. Because equivalent test weights were not available for the durability vehicles being evaluated, inertia weight class was used to calculate the power-to-weight ratios for both the reference vehicles and the LDTs. The axle ratios were 23% higher for the LDTs.

The predicted results in Table Chrysler-2 indicate that the B/C engines with emission control system 1 will be able to comply with the standards using both the lowest and average dfs.

Ford

Light-Duty Vehicles

Ford summarized their plans for high altitude compliance as shown in Table Ford-1 [6 at Attachment II].

TABLE Ford-1

HIGH ALTITUDE COMPLIANCE PLAN[1] - PASSENGER CAR

	1982	1983
Small 1-4	Non FB/Aneroid[2]	Non FB/Aneroid[2]
Large 1-4	Non FB/Aneroid[3]	Non FB/Aneroid[3]
1-6	Non FB/Aneroid	Non FB/Aneroid
V-8	Non FB/Aneroid FB/Electronic	Non FB/Aneroid FB/Electronic

1 Compliance at high altitude achieved by use of higher axle ratios where required.

2 Except for EFI equipped engines which will have FB and EEC. FBC under consideration.

3 Except for turbocharged 1-4 which may be equipped with FBC and MCU.

The following statement and data from Ford indicate that in their opinion it is technically feasible for Ford to meet the high altitude standards.

> The data in Table 2 [Ford-2] indicates that Ford's current "altitude compensated electronic calibrations" are capable of achieving the standards EPA has proposed at altitude. The test results on vehicle #4 indicate that less costly "aneroid compensated non-electronic calibrations" also comply [6 at Attachment III].

TABLE Ford-2

Vehicle #	Vehicle Description	Axle Ratio	Test Location	# Tests	CVS Emissions g/mi HC	CO	NOx
4	4.2L A/T 3250 I.W. 49-S Calibration Compensated (Aneroid)	2.26	Dearborn	1	0.23	1.1	0.87
			Denver	2	0.38	1.9	0.90
5	5.8L FIOD 4500 I.W. 49-S Calibration Compensated (EEC II)	2.73	Dearborn	1	0.17	0.9	1.64
			Denver	2	0.19	2.3	1.59
6	5.0L FIOD 4250 I.W. Calif. Calibration Compensated (CFI)	3.08	Dearborn	1	0.12	1.2	0.63
			Denver	2	0.22	3.6	0.46

In reference to their compliance plans for high altitude, Ford said,

> To carry out this plan, the only additional change that need be made to the proposed rules is to make it clear that unique axles are a permissible element of an altitude "modification" [6 at Attachment II].

Although Ford tested six vehicles at high altitude, the three vehicles included in Table Ford-2 are the only ones that are representative of Ford's plans as listed in Table Ford-1. The axle ratio for these vehicles are 2.26, 2.73, and 3.08. The data in Table Ford-2 indicate that these vehicles are well below the high altitude standards for HC and CO, even with the axle ratios of 2.26 and 2.73. It should be noted that the lower the axle ratio, the lower the increase in CO emissions. Car #4, with a 2.26 axle ratio, had a 73% increase in CO. Car #5, with a 2.73 ratio, increased by 156% and car #6, with a 3.08 ratio and central fuel injection, increased by 200%. Although the EPA technical staff does not take the limited amount of data to be indicative of the general case, it has concluded that Ford failed to show that unique axle ratios are essential for compliance with the high altitude standards.

Pass/Fail Analysis of the Ford 1.3/1.6L Engines

Based on information in their CO waiver request, Ford is expected to use an open-loop AIR/3W/OC/EGR emission control system with the 1.3 and 1.6L engines. No altitude factors have been developed for this emission control system and Ford has not submitted high altitude data for these engines. Since these engines use the same emission control systems and are of the same configuration (I-4), they were analyzed as a group.

Ford has submitted high and low altitude test data for an engine with an aneroid compensated carburetor (see vehicle #4 in Table Ford-2). Ford said that "the test results on vehicle #4 indicate that less costly 'aneroid compensated non-electronic calibrations' also comply [6 at Attachment III]." Ford did not indicate the type of catalysts vehicle #4 was equipped with. Table Ford-1 shows the information Ford supplied on the small I-4, which include the 1.3L and 1.6L engines. These engines have the same devices for altitude compliance as vehicle #4, but according to 1980 certification information, vehicle #4 is equipped with AIR/OC/EGR, rather than with the AIR/3W/OC/EGR system, which is expected to be used with the small I-4.

This type of emission control system usually runs leaner than stoichiometric whereas Ford indicated that the AIR/3W/OC/EGR system is calibrated to operate at stoichiometry [3 at 40011]. If this is still true of the Ford AIR/3W/OC/EGR system, the altitude factors developed from vehicle #4 would not be appropriate to use with these engines. On the other hand, if Ford is calibrating their 3W+OC system "lean" to operate primarily as an oxidation catalyst system, it may be an appropriate factor to use. Since Ford inferred that the results from vehicle #4 are representative of their open-loop capabilities, they may now be using a lean calibration strategy.

If Ford calibrates the 1.3L and 1.6L engines to operate at stoichiometry, the technical staff concludes that it does not have enough information to predict the ability of this emission control system to compensate for altitude.

A method 3 analysis was done using the AIR/OC/EGR altitude factors developed from vehicle #4 in case the 1.3L and 1.6L engines are calibrated lean. The altitude factors may not even be valid for this situation. In any case, the predicted results in Table Ford-3 indicate that these engines will pass using the lowest dfs or the average dfs.

Pass/Fail Analysis of the Ford 2.3L Engine

Based on Ford testimony at the high altitude hearings, the 2.3L engine is expected to use either a FBC/AIR/3W/OC/EGR or an AIR/3W/OC/EGR emission control system. Because of the questionable validity of using the AIR/OC/EGR altitude factor with the open-loop 3W+OC control system, the open-loop system was not evaluated.

Since there were no emission data vehicle test results available for the FBC/AIR/3W/OC/EGR control system, a method 3 analysis was used. The dfs and the extrapolated 4K test results were taken from one durability vehicle. The altitude factor represents an average of the factors calculated from Chrysler and Ford data. The Ford altitude factors were derived from a vehicle with Ford's EEC II emission control system. The 2.3L engine is equipped with the less sophisticated MCU system. The average altitude factors from the Chrysler and Ford vehicles were more conservative than from the Ford EEC II data only, and was felt to be more appropriate for use with the 2.3L engine.

The predicted results in Table Ford-3 indicate that this engine will pass using the results from one durability vehicle.

Pass/Fail Analysis of the Ford 2.3L Turbocharged Engine

Based on their CO waiver request, it is possible that Ford may use either FBC/AIR/3W/OC/EGR or AIR/3W/OC/EGR for the 1982 model year and

TABLE FORD-3

Analyses by Methods 2 and 3 of

Ford LDVs

DISP	EMISSION CONTROL SYSTEM	CERT. 4K Data*			HIGH TO LOW ALTITUDE FACTORS			CERT DFs*			PREDICTED RESULTS			PASS-FAIL				COMMENTS
		HC	CO	NOx	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx	HC	CO_{11}**	$CO_{7.8}$	NOx	
1.6	AIR/3W/OC/EGR				1.65	1.73	1.03				0.39	4.6	0.9	P	--	P	P	Lowest dfs
											0.39	4.6	1.0	P	--	P	P	Avg dfs (2)
2.3	FBC/AIR/3W/OC/EGR				1.47	2.63	1.00				0.53	5.7	0.8	P	--	P	P	One Veh
3.3	1				*	*	*				0.40	2.7	0.6	P	--	P	P	Lowest dfs
											0.53	4.8	0.6	P	--	P	P	Avg dfs (3)

* Not Yet Publicly Released.

** Engine with a CO waiver have a "P" or "F" in this column.
Engines without a CO waiver have a "--" in this column.

electronic fuel injection (EFI) for the 1983 MY. No data were available for the EFI system. Data were available for the AIR/3W/OC/EGR system, but as explained in the pass/fail analysis for 1.3 and 1.6L engines, the technical staff has little confidence that the AIR/OC/EGR altitude factors would be valid to use with the open-loop AIR/3W/OC/EGR system. Also, since the AIR/OC/EGR altitude factor was developed from data on naturally aspirated engines, it could not be used with this engine even if it were calibrated to operate lean. The FBC/AIR/3W/OC/EGR altitude factors were also developed from data for naturally aspirated engines and may not be appropriate for use with a turbocharged engine.

The technical staff concludes that it does not have enough information to predict the ability of this engine to comply with the proposed standards.

Pass/Fail Analysis of the Ford 3.3L Engine

Based on testimony at the high altitude hearings, and on 1981 certification information, this engine is expected to have three different emission control systems. These include FBC/AIR/3W/OC/EGR, AIR/3W/OC/EGR and emission control system 1*. The feedback carburetor system was not evaluated because dfs were not available. The open-loop 3W+OC system was also not evaluated due to the questionable validity of using the AIR/OC/EGR factors with it.

Although it is considered to be the least likely control system to be used, emission control system 1 was evaluated. Dfs from three durability vehicles and 4K test results from 3 emission data vehicles were used in a method 2 analysis.

Based on the predicted results listed in Table Ford-3, the technical staff concludes that the 3.3L engine with emission control system 1 will have the ability to comply with the proposed standards.

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* Not yet publicly released.

Pass/Fail Analysis of the Ford 4.2L, 5.0L and 5.8L Engines

Based on Ford's high altitude hearing testimony, these engines are expected to be equipped with three different emission control systems. These include AIR/3W/OC/EGR, FBC/AIR/3W/OC/EGR, and CLTBI*/AIR/3W/OC/EGR.

All three engines use the same model feedback carburetors for their closed-loop carburetor systems and the same model open-loop carburetors for their open-loop emission control systems. Also, the 4.2L and 5.0L engines were certified in the same engine families in 1980. Since it is preferable to use actual high altitude data in a method 1 analysis rather than the method 2 and method 3 alternatives, and because such data were not available for each engine-control system combination, these three engines were evaluated as a group.

Tables Ford-2 and Ford-4 indicate that vehicle #4 is equipped with an aneroid compensated carburetor and an AIR/OC/EGR emission control system.

The emission control system description is from 1980 certification information. Using a method 1 analysis, the predicted results listed in Table Ford-4 indicate that, using 1981 certification dfs, this engine group has the ability to comply with the standards with an aneroid compensated carburetor, and an AIR/OC/EGR emssion control system.

Ford did not provide high altitude test data for their open-loop AIR/3W/OC/EGR system. Because of the questionable validity of using the AIR/OC/EGR altitude factor for the open-loop 3W+OC system, this system was not evaluated.

Ford did provide high altitude test data on their closed-loop throttle body fuel infection (CLTBI) which Ford refers to as central fuel injection (CFI). These data were evaluated using a method 1 analysis. The

*CLTBI is an abbreviation for closed-loop throttle body injection.

TABLE FORD-4

Method 1 Analysis of

Ford LDVs

Vehicle #	DISP.	EMISSION CONTROL SYSTEM	HIGH ALTITUDE TEST RESULTS			DETERIORATION FACTORS*			PREDICTED RESULTS			PASS-FAIL				COMMENTS
			HC	CO	NOx	HC	CO	NOx	HC	CO	NOx	HC	CO_{11}**	$CO_{7.8}$	NOx	
			-------g/mi-------						-------g/mi-------							
4	4.2	AIR/ OC/EGR	0.38	1.9	0.90				0.38	2.2	0.9	P	--	P	P	Lowest dfs
									0.60	3.1	0.9	F	--	P	P	Average dfs (4)
5	5.8	FBC/AIR/3W/OC/EGR	0.19	2.3	1.59				0.30	2.3	1.6	P	--	P	F	Lowest dfs
									0.24	2.4	1.6	P		P	F	Average dfs (2)
6	5.0	CLTBI/AIR/3W/OC/EGR	0.22	3.6	0.46				0.35	3.6	0.5	P	--	P	P	Lowest dfs
									0.37	4.4	0.5	P	--	P	P	Average dfs (2)

* Not Yet Publicly Released.

** Engines with a CO waiver have a "P" or "F" in this column. Engines without a CO waiver have a "--" in this column.

predicted results listed in Table Ford-4 indicate that this engine group also has the ability to comply with the standards using the CLTBI/AIR/3W/OC/EGR emission control system.

The FBC/AIR/3W/OC/EGR emission control system for this engine group was evaluated using the high altitude test results from vehicle #5 which was equipped with the 5.8L engine. The predicted results in Table Ford-4 indicate that vehicle #5 would fail the 1981 low and high altitude NOx standard of 1.0. This was a 1980 vehicle which was probably calibrated for the 1980 NOx standard of 2.0 and the data in Table Ford-2 shows that NOx decreased slightly in Denver. It is the technical staff's judgement that a vehicle with this control system calibrated for the 1981 low altitude standards will be able to comply with the 1982-1983 high altitude standards and should have the same ability to compensate for altitude on the 4.2L and 5.0L engines as it does on the 5.8L engine.

Ford

Light Duty Trucks

Based on 1981 certification information, Ford is expected to market the four engines and two emission control systems listed below:

Displacement	Emission Control System
A	1
A	2
B	1
B	2
C	1
C	2
D	1
D	2

Pass/fail analyses for 49-state emission control systems were also included.

Pass/Fail Analysis for the Ford A-1 LDT Engine

The A engine equipped with emission control system 1 was represented by seven emission data vehicles and seven durability vehicles. The altitude factors for this engine were developed from light duty vehicle data. The LDTs had a hp/ETW ratio 29% lower than the reference vehicle, and the axle ratio for the trucks was 34% higher. A method 2 analysis was used for this engine.

The predicted results listed in Table Ford-5 indicate that the A-1 engine will pass the 1982 standards using either the lowest or average dfs, but will fail the 1983 HC standard in both cases. Based on these

Table Ford-5

Ford LDT

DISP.*	Emission Control System*	HP/ETW RATIOS Ref. Veh.* ($\times 10^{-2}$)	HP/ETW RATIOS Cert. 4K Veh's.* ($\times 10^{-2}$)	HP/ETW RATIOS LDT to 4K Ref. Veh. (%)	AXLE RATIOS Ref. Veh.* ($\times 10^{-2}$)	AXLE RATIOS Cert. 4K Veh's.* ($\times 10^{-2}$)	AXLE RATIOS LDT to 4K Ref. Veh. (%)	Cert. 4K Tests* HC	Cert. 4K Tests* CO	Cert. 4K Tests* NOx	High to Low Altitude Factors* HC	High to Low Altitude Factors* CO	High to Low Altitude Factors* NOx	Cert. dfs	Predicted Results HC	Predicted Results CO	Predicted Results NOx	Pass-Fail 1982 HC	Pass-Fail 1982 CO	Pass-Fail 1982 NOx	Pass-Fail 1983 HC	Pass-Fail 1983 CO	Pass-Fail 1983 NOx	Comments
								---g/mi--							------g/mi-------									
A	1			-29			+34								1.16	10	1.6	P	P	P	P	P	P	Lowest dfs
															1.52	11	1.8	P	P	P	F	P	P	Average dfs (7)
A	2			-20			+11								0.3	6	0.8	P	P	P	P	P	P	One Vehicle
D	1			-11			+48								1.6	15	1.8	P	P	P	F	F	P	Lowest dfs
															1.9	15	2.0	P	P	P	F	F	P	Average dfs (2)
D	2			0			+28								0.2	1	0.8	P	P	P	P	P	P	Lowest dfs
															0.3	1	0.8	P	P	P	P	P	P	Average dfs (3)

*Not Yet Publicly Released.

results, the technical staff concludes that the A engine with emission control system 1 now has the ability to pass the 1982 standards, but further development will be required to comply with the 1983 standards.

Emission control system 1 is a 49-state control system. Since the Federal or 49-state HC standard of 1.7 g/mi is 0.7 g/mi higher than the 1983 proposed high altitude standard of 1.0 g/mi, it is not surprising that it fails the 1983 proposed standards. Considering the development time remaining for the 1983 MY, it is possible that this engine can also be made to comply with the 1983 proposed standards. Also, engine A-2 with emission control system 2 now has the ability to meet both the 1982 and 1983 proposed standards.

Pass/Fail Analysis for the Ford A-2 LDT Engine

The A engine, equipped with emission control system 2, was represented by five emission data vehicles and one durability vehicle. A method 2 analysis was used for this engine.

The hp/ETW ratio was 20% higher for the reference vehicle than for the average hp/ETW ratio for the five emission data vehicles. The rear axle ratio was 11% higher for the LDTs. The predicted results are 0.3 g/mi HC, 6 g/mi CO and 0.8 g/mi NOx (see Table Ford-4). The technical staff concludes that this engine has the ability to comply with the standard.

Pass/Fail Analysis of the Ford B, C & D-1 LDT Engines

The B, C, and D engines with emission control system 1 are represented by nine emission data vehicles equipped the D engine. Since the emission control system and engine configuration for B, C, and D engines are similar, the same model carburetor is used for all three, and the B and C engines were certified in the same engine family in 1980, the technical staff felt it would be appropriate to analyze these engines as a group using data from the D engines. No low mileage data meeting the criteria discussed in section III were available for the B and C engines.

Dfs were available from three durability vehicles, but only two of the vehicles were used in the analysis because the third had a NOx df greater than 4.0. The altitude factors were developed from a LDV having a hp/ETW ratio 11% greater than the trucks, but its axle ratio was 48% lower. These data were used in a method 2 analysis.

The predicted results in Table Ford-2 indicate that these engines will pass the 1982 standards using both the lowest dfs and the average dfs, but will fail the 1983 standards using either dfs. This is a 49-state emission control system. As explained in the analysis of the A-1 engine, the 1981 49-state low altitude HC and CO standards are significantly higher than the 1983 high altitude standards. Considering the standards these engines were calibrated to, and the development time remaining for the 1983 MY, it is possible that these engines can also be made to comply with the 1983 standards. Also, these engines were predicted to be able to comply with both the 1982 and 1983 standards when used with emission control system 2.

Pass/Fail Analysis of the B, C, D-2 Engines

The B, C and D engines with emission control system 2 were represented by one emission data vehicle and three durability vehicles equipped with the the D-2 engine. These data were used in a method 2 analysis. For the reasons explained in the previous pass/fail analysis (B, C, & D-1), these engines were evaluated as a group. As for engine A-2, the altitude factors were developed from light duty vehicle data. In this case, the hp/ETW ratio was one percent higher for the trucks, and the axle ratio was 28% higher for the trucks.

The predicted results in Table Ford-2 indicate that these engines are well below the standards. Based on these results, the technical staff concludes that the B, C, and D engines with emission control system 2 have the ability to comply with the proposed standards.

General Motors

Light-Duty Vehicles

GM has not made technical feasibility an issue in their comments on the 1982-1983 proposed high altitude regulations. GM described their high altitude development program as follows:

> Resulting test data from vehicles representing the broad spectrum of General Motors passenger cars are displayed in Figure 1. These data show average emissions at Denver's altitude of 0.49 g/mi exhaust hydrocarbons, 6.7 g/mi carbon monoxide, and 0.70 g/mi NOx. Those average emission levels compare very favorably with the proposed 1982-1983 standards of 0.57, 7.8, and 1.0 g/mi HC, CO, and NOx, respectively. Clearly, insofar as General Motors passenger cars are concerned, the purpose of the proposed regulations will be accomplished, not in 1982, but in 1983 without any regulations [4 at 88].

EPA used a method 1 analysis to evaluate the capability of GM's C-4 emission control system for altitude compensation. The technical staff did not make an effort to predict the engine displacements and emission control systems which GM would be using in the 1982-1983 model years. Because GM characterized the data they presented as "representing the broad spectrum of General Motors passenger cars," the technical staff did pass/fail analyses only for those engine displacements for which GM supplied high altitude test results and considered these data as representative of GM's capabilities in complying with the proposed high altitude standards.

Since GM indicated that dual bed catalysts would be required with their C-4 system to comply with the 3.4 g/mi CO standard at low altitude in 1981 and 1982 [30 at 68-72], only 1981 durability vehicles with both three-way and oxidation catalysts were used in this analysis.

Pass/Fail Analysis of the GM 1.6L Engine

GM submitted high altitude test data from two 1.6L development vehicles. As the predicted results in Table GM-1 show, this engine is projected to fail the standards using either the lowest or average dfs.

It should be noted that the 1.6L engine has a CO waiver for the 1981 MY and that the high altitude tests were conducted in September of 1979. Because the 1.6L engine does not have a CO waiver for the 1982 MY, its high altitude emission results were evaluated against the 7.8 CO standard. Since these vehicles were tested in September of 1979, it is possible that their low altitude CO emissions were above the 3.4 CO standard. If this were the case, these vehicles would naturally have difficulties meeting the 7.8 CO standard at high altitude. The predicted results in Table GM-1 indicate that the 1.6L engine can comply with the 11 g/mi CO standard using the lowest dfs. Using the average dfs from three durability vehicles, the predicted results indicate the engine will fail CO. One of the three vehicles has a CO df above 8.0 and several other vehicles were line crossing the 3.4 CO standard. It is not surprising that vehicles complying with the 7.0 CO standard at low altitudes would have difficulty complying with a 7.8 CO standard at high altitude.

Considering the possiblity that the test vehicles had low altitude CO levels above the 3.4 g/mi standard, the EPA technical staff concludes that with the data available, it cannot predict the 1.6L engine's ability to compensate for altitude.

Pass/Fail Analysis of the GM 2.5L Engine

GM submitted high altitude test data from two 2.5L vehicles which were tested in July, 1979. These data were used in a method 1 analysis. The predicted results in Table GM-1 indicate that these vehicles will pass using the lowest dfs. Using the average dfs from three 1981 certification durability vehicles, the predicted results indicate the 2.5L engine will fail.

Table GM-1

General Motors LDV

DISP.	Emission Control System	High Altitude Test Results HC	CO	NOx	Deterioration Factors* HC	CO	NOx	Predicted Results HC	CO	NOx	Pass-Fail HC	CO_{11}**	$CO_{7.8}$	NOx	Comments
		------g/mi-----						-----g/mi----							
1.6	FBC/AIR/3W/OC/EGR	0.28	6.64	0.42				0.40	10.7	0.5	P	--	F	P	Lowest dfs
								0.46	26.6	0.6	P	--	F	P	Average dfs (3)
2.5	FBC/AIR/3W/OC/EGR	0.46	4.95	0.78				0.57	6.6	0.8	P	--	P	P	Lowest dfs
								0.60	7.5	0.9	F	--	P	P	Average dfs (3)
3.8	FBC/AIR/3W/OC/EGR	0.34	4.10	0.68				0.41	4.4	0.8	P	***	P	P	Lowest dfs
								0.46	4.6	0.8	P	***	P	P	Average dfs (4)
4.3	FBC/AIR/3W/OC/EGR	0.36	3.46	0.71				0.52	4.7	0.7	P	--	P	P	Lowest dfs
								0.53	4.5	0.8	P	--	P	P	Average dfs (6)
4.4	FBC/AIR/3W/OC/EGR	0.52	7.90	0.56				0.52	9.4	0.6	P	--	F	P	Lowest dfs
								0.55	8.8	0.6	P	--	F	P	Average dfs (2)
4.9	FBC/AIR/3W/OC/EGR	0.35	3.27	0.64				0.35	3.5	0.8	P	--	P	P	Lowest dfs
Standard								0.46	4.2	0.7	P	--	P	P	Average dfs (3)
4.9	FBC/AIR/3W/OC/EGR	0.36	2.8	0.60				0.36	3.0	0.7	P	--	P	P	Lowest dfs
High Performance								0.47	3.6	0.7	P	--	P	P	Average dfs (3)

Table GM-1

(Cont.)

DISP.	Emission Control System	High Altitude Test Results			Deterioration Factors			Predicted Results			Pass-Fail				Comments
		HC	CO	NOx	HC	CO	NOx	HC	CO	NOx	HC	CO_{11}**	$CO_{7.8}$	NOx	
		------g/mi-----						-----g/mi----							
4.9	FBC/AIR/3W/OC/EGR	0.72	14.8	0.63				0.87	17.3	0.7	F	--	F	P	Lowest dfs
Turbocharged								0.90	17.0	0.7	F	--	F	P	Average dfs (2)
5.0	FBC/AIR/3W/OC/EGR	0.26	2.66	0.68				0.29	2.7	0.7	P	--	P	P	Lowest dfs
								0.40	3.8	0.8	P	--	P	P	Average dfs (9)
5.7	FBC/AIR/3W/OC/EGR	0.22	1.94	0.52				0.24	1.9	0.5	P	--	P	P	Lowest dfs
								0.34	2.8	0.6	P	--	P	P	Average dfs (9)
6.0	FBC/AIR/3W/OC/EGR	0.49	5.7	0.57				0.66	5.8	0.7	F	--	P	P	Lowest dfs
								0.91	12.8	0.7	F	--	F	P	Average dfs (3)

* Not Yet Publicly Released.

** Engines with a CO waiver have a "P" or "F" in this column. Engines without a CO waiver have a "--" in this column.

*** 3.8L Chevrolet engine does not have a CO waiver.

Considering the development time available since the July test date, and the predicted results using the lowest dfs, the technical staff concludes that the 2.5L engine will have the technical capability to meet the proposed standards.

Pass/Fail Analysis of the 3.8L Engine

GM submitted high altitude test data from two 3.8L development vehicles which were tested in July, 1979. Dfs were applied only from durability vehicles with dual bed catalysts. These were all naturally aspirated Chevrolet engines. The predicted results listed in Table GM-1 indicate that this engine passes using either the lowest dfs or the average dfs from four 1981 certification durability vehicles.

The technical staff concludes that the 3.8L engine has the ability to comply with the proposed high altitude standards.

Pass/Fail Analysis of the GM 4.3L Engine(s)

GM submitted test data from six vehicles equipped with 4.3L engines. GM has two 4.3L engines, but did not identify which of these engines were in the development vehicles. Deterioration factors from six 1981 certification durability vehicles were used in this analysis. Dfs from both 4.3L engines were included in the average. The predicted results show that this engine complies with the standards using either the average dfs or the lowest dfs.

Based on the results from the method 1 analysis, the technical staff concludes that the 4.3L engine(s) has the ability to comply with the proposed standards.

Pass/Fail Analysis of the GM 4.4L Engine

GM submitted high altitude test data from two cars with 4.4L engines. The predicted results in Table GM-1 indicate that this engine will not comply with the proposed standards, regardless of whether the lowest dfs or the average dfs of the two certification durability vehicles are used. It should be noted that three durability vehicles met the criteria for inclusion discussed in section 3, but one of these was not used because its projected CO df was a negative value according to the EPA Certification Status Report of July 11, 1980.

At the high altitude hearing, GM stated that the 4.4L engines were having a problem at high altitude because the range of authority was not sufficient and went on to say that "it has been necessary to extend the range and we expect that if we go back to altitude, that the car should function satisfactory [4 at 107]."

Since additional data have not been submitted for vehicles which have been modified by having their range of authority extended, the technical staff does not have sufficient data to predict the pass/fail results of this engine.

Pass/Fail Analysis of the GM Standard 4.9 Engine

GM submitted high altitude test data for three different 4.9L engines. These included the turbocharged engine, the high performance engine, and the standard 4.9L engine. This section is for the standard engine.

The technical staff did not have sufficient information to determine whether the standard 4.9L and the high performance 4.9L are certified within the same engine family or are certified separately. In this analysis, dfs from three naturally aspirated durability vehicles with 4.9L engines were used in evaluating both the standard and the high performance engine. The low mileage, high altitude test data from each of these engines were evaluated separately, although with the same dfs.

For the standard engine, the predicted results in Table GM-1 indicate that this engine passes the standards using either the lowest or the average dfs.

Pass/Fail Analysis of the GM High Performance 4.9L Engine

GM submitted high altitude test data from two cars with the high performance 4.9L engine. Using the average or the lowest dfs from three 1981 certification durability vehicles, which represented all 4.9L engines, except for those with turbochargers, the predicted high altitude results for these vehicles indicate they can comply with the standards.

Based on the predicted results listed in Table GM-1, the technical staff concludes that the 4.9L high performance engine has the ability to comply ~~with the proposed standards.~~

Pass/Fail Analysis of the GM 4.9L Turbocharged Engine

GM submitted high altitude test data from two vehicles with the turbocharged 4.9L engine. A method 1 analysis using the lowest or the average dfs from two certification durability vehicles indicate that this engine will not pass the standards.

In a written response to questions from the EPA panel at the high altitude hearing regarding this engine, GM offers the following explanation for the high emissions levels:

> These vehicles were in a relatively early stage of development when the tests were run, and we are confident that emissions from current configurations of those turbocharged engines would be appreciably lower. However, we have not yet obtained high altitude emissions data on the refined systems [11 at 3].

The situation for this engine is similar to that for the 1.6L engine. GM has made two CO waiver requests for each of these engines. In its waiver application for the 4.9L engine, GM indicated it was having difficulty complying with the 3.4 CO standard at low altitudes. It's possible that the vehicles tested at high altitude in July, 1979 were not able to comply with the low altitude standards and in turn, would also have difficulty complying with the high altitude standards for HC and CO.

Because the technical staff has not reviewed high altitude data for any other GM turbocharged engine with the C-4 emission control system, and has not evaluated more recent development data for this engine, the technical staff concludes that there is insufficient data on which to base a judgement for this engine.

Pass/Fail Analysis of the 5.0/5.7L Engine

GM submitted high altitude test data from two cars with 5.0L engines and two cars with 5.7L engines. GM has two different 5.0L engines and also two different 5.7L engines, but it did not identify which engines were in the development vehicles. Historically, the Chevrolet has certified its 5.0 and 5.7L engines in the same engine family. For this analysis, all GM durability vehicles with 5.0 or 5.7L engines which met the criteria explained in Section 3 were included in the average df. Nine vehicles, including Chevrolets and Oldsmobiles, were included in this average. The same dfs were then used to evaluate both the 5.0 and the 5.7L engines, although they were evaluated separately. The predicted results in Table GM-1 indicate that the 5.0L engine will pass using either the lowest dfs or the average dfs. Using the same dfs and the 5.7L engine high altitude test data, the predicted results also indicate that this engine will comply using either combination of dfs.

Based on the predicted results listed in Table GM-1, the technical staff concludes that these engines have the ability to comply with the high altitude standards.

Pass/Fail Analysis of the GM 6.0L Engine

GM submitted high altitude test data from one development vehicle equipped with the 6.0L engine. This car was tested in August, 1979. Using the lowest dfs and the average dfs from three durability vehicles, the predicted results in Table GM-1 indicate that this engine will fail using either the lowest dfs or the average dfs.

GM has several options to improve the high altitude performance of their C-4 emission control system. These include keep-alive memory, altitude compensated spark timing, a manifold absolute pressure sensor, and throttle position corrected by barometer. EPA is not aware of which options, if any, were included on the 6.0L development vehicle.

Considering the development time remaining since the test date and questions regarding the emission control system, the technical staff concludes that it doesn't have enough information to predict the present ability of this engine to comply with the proposed standards.

General Motors

Light Duty Trucks

Based on 1981 certification information, General Motors is expected to market the following LDT engines in the 1982-1983 model years:

	Displacement	Emission Control System
1.	A	1
2.	B	3
3.	C/D	3

Pass/Fail Analysis of the GM A LDT Engine

The A engine is expected to be equipped with emission control system 1. ~~Since no altitude factors were available for vehicles using~~ this LDT engine, a method 4 analysis was used. Although this emission control system is not exactly the same as GM's LDV control system, the technical staff feels that its ability to compensate for altitude should be almost as effective as the LDVs. Also, the light duty truck standards are considerably less stringent than the light duty vehicle standards. Therefore, based on GM's high altitude data for their LDVs equipped with the A engine, the EPA technical staff's judgement is that this engine will be able to meet the proposed LDT standards.

Pass/Fail Analysis of the GM B LDT Engine

This engine is expected to be equipped with emission control system 3. Dfs from four durability vehicles and 4K test results from two emission data vehicles were used in a method 2 analysis.

The altitude factors used in this analysis were calculated from LDV data. As Table GM-2 shows, horsepower-to-equivalent test weight ratios for the LDV was 19% higher than for the LDT emission data vehicles, but

TABLE GM-2

General Motors LDT

DISP.*	Emission Control System*	HP/ETW RATIOS Ref. Veh.* ($X 10^{-2}$)	HP/ETW RATIOS Cert. 4K Veh's.* ($X 10^{-2}$)	HP/ETW RATIOS LDT to 4K Ref. Veh. (%)	AXLE RATIOS Ref. Veh.* ($X 10^{-2}$)	AXLE RATIOS Cert. 4K Veh's.* ($X 10^{-2}$)	AXLE RATIOS LDT to 4K Ref. Veh. (%)	Cert. 4K Tests* HC	Cert. 4K Tests* CO	Cert. 4K Tests* NOx	High to Low Altitude Factors* HC	High to Low Altitude Factors* CO	High to Low Altitude Factors* NOx	Cert. DF's*	Predicted Results HC	Predicted Results CO	Predicted Results NOx	Pass-Fail 1982 HC	Pass-Fail 1982 CO	Pass-Fail 1982 NOx	Pass-Fail 1983 HC	Pass-Fail 1983 CO	Pass-Fail 1983 NOx	Comments
								---g/mi--							-------g/mi-------									
A	1																							No Altitude Factors
B	3		-19				+21								0.4	8	1.0	P	P	P	P	P	P	Lowest dfs
															0.5	10	1.0	P	P	P	P	P	P	Avg dfs (4)
C/D	3		-5				+21								0.5	3	1.8	P	P	P	P	P	P	Lowest dfs
															0.8	4	1.5	P	P	P	P	P	P	Avg dfs (7)

* Not Yet Publicly Released.

the axle ratios were 21% higher for the LDTs. The predicted results in Table GM-2 indicate that this engine will easily pass the standards.

Pass/Fail Analysis of the GM C/D LDT Engines

Engines C and D were grouped together because they have previously been certified in the same engine families. These engines are expected to be equipped with emission control system 3. The dfs from seven durability vehicles and the 4000 mile test results from one emission data vehicle were used in a method 2 analysis.

The hp/ETW ratio for the reference vehicle was 5% higher than for the certification LDTs, but the axle ratio for the LDTs was 21% higher.

The predicted results listed in Table GM-2 indicate that these engines, with emission control system 3, will be able to comply with the standards.

Honda Motor Co. Ltd.

The technical staff assumes that the following engines and emission control systems will be used by Honda in the 1982 and 1983 model years:

Displacement	System
A	1
B	2
C	3

The following statement was excerpted from the Honda submittal:

> Honda Motor Co. Ltd. currently offers high-altitude versions of most of their current vehicles. These vehicles are manufactured on the production line and offered economically to high altitude customers [14 at 1].

Honda has used an "Air Jet Controller" [16 at 21] modification (an aneroid) to the carburetor assembly in order to accomplish A/F ratio control on their production vehicles for high altitude since 1977. The potential effectiveness of this control, as demonstrated on the 1.8L, 49-state vehicle adjusted for df, is shown in Table Honda-1. HC emissions in the range of 0.18 to 0.28 gpm and CO emissions in the range of 5 to 6 gpm (with a new catalyst and EGR) are significantly below the interim high altitude standards for the 1983 model year (0.57 HC, 7.8 CO). NOx levels are also acceptable and below the 1.0 gpm standard established for the 1983 MY.

This technology is considered by the technical staff to be transferable to the other engines assumed to be marketed by Honda in the 1982 and 1983 model years.

Table Honda-1

Honda Motor Co. Ltd.

High Altitude Emission Characteristics
With New Catalyst and EGR

[16 at 21]

	Test Location	75 FTP CO	75 FTP HC	75 FTP NOx
		g/mi	g/mi	g/mi
1.8L 49-states 5MT	Low Altitude	2.51	0.170	0.683
	High* Altitude	5.8	0.278	0.450
1.8L 49-states 3AT	Low Altitude	3.40	0.129	0.559
	High* Altitude	5.10	0.176	0.599

*With Air Jet Controller

This technical assessment by method 1, of Honda's technical capability to comply with the 1982 and 1983 model year high altitude standards, gives the technical staff confidence that Honda does indeed have the required technological capability to comply with the interim high altitude standards in 1982 and 1983.

International Harvester (IH)

The technical staff assessed the technological capability of this manufacturer for meeting the more stringent light-duty truck (LDT) standards of 1.0 HC, 14 CO, and 2.3 NOx, considered for the 1983 MY, on the basis of high altitude emissions data supplied by the manufacturer. LDT standards for the 1982 MY are more lenient at 2.0 HC, 26 CO, and 2.3 NOx. Since the technology considered here could be applied to meet the less stringent 1982 standards, compliance with the 1982 standards is considered assured if IH can comply with the 1983 standards.

The technical staff assumes that that the following gasoline engine families and emission control systems will be marketed by IH in the 1982 and 1983 model years:

	Displacement	System
1.	A	1
2.	B	1
3.	C	1

At the public hearing held in Denver, Colorado on March 5 and 6, IH was requested to submit LDT high altitude data. These data were provided and are shown in Table IH-1. These data apply to the 345 cubic inch engine in the 5000 pound IW Scout Traveler. The emission control system included AIR-OC-EGR, and is representative of 1977 technology [13 at Attachment]. The high altitude emission data in Table IH-1 were developed in 1977. The vehicles were tested at high (5000 pound) inertia weights.

Since the altitude data provided by IH were not of recent origin, the technical staff used method 4 in determining IH's technical capability to comply with the more stringent 1983 high altitude standards of 1.0 HC, 14 CO, and 2.3 NOx. IH has demonstrated that HC, CO, and NOx can indeed be controlled at high altitude to the interim standard levels by use of different carburetor modifications or adjustment strategies (Table IH-1). As this capability was demonstrated in 1977 on the large

Table IH-1

International Harvester

HIGH ALTITUDE TEST DATA OBTAINED AT AUTOMOTIVE TESTING LABORATORIES (DENVER) ON SCOUT LDT VEHICLES DURING JUNE, 1977

[13 at Attachment]

Vehicle #237 - Scout Traveler with: V-345 CID gas engine, 3-speed automatic transmission. 3.54:1 final drive ratio. RLHP = 14.1 IW = 5000# Emission Control System: Air Injection, Catalyst, EGR

'75 FTP (g/mi)			
HC	CO	NOx	Remarks
.51	7.16	1.35	Fixed high altitude metering
.50	6.43	1.24	Fixed high altitude metering
.54	4.40	1.43	Switch in high altitude position
.44	4.49	1.62	Switch in high altitude position
.45	5.61	1.43	Switch in high altitude position
.47	4.26	2.02	Remetered EGR
.42	3.90	1.82	Recalibrated Accelerator Pump
.42	3.50	1.80	Recalibrated Accelerator Pump
.49	4.94	1.93	Metering Same as EM 93
.49	5.02	1.67	Metering Same as EM 93

Vehicle #203 - Scout Traveler with: V-345 CID engine, 3-speed manual transmission, 3.73:1 final drive ratio. RLHP = 14.1 IW = 5000# Emission Control System: Air Injection, Catalyst, EGR

'75 FTP (g/mi)			
HC	CO	NOx	Remarks
.67	15.9	.92	Fixed high altitude metering
.71	15.9	1.01	Fixed high altitude metering
.64	12.6	1.22	Switch in high altitude position
.60	8.49	1.66	Carburetor Remetered
.57	6.38	1.55	20, 30 mph shift points used

Table IH-1

International Harvester
(continued)

'75 FTP (g/mi)			
HC	CO	NOx	Remarks
.54	5.4	1.81	Run without air injection divert on decels
.48	5.58	2.04	Run without air injection divert on decels
.59	6.35	1.54	Metering same as EM 92
.60	7.75	1.52	Metering same as EM 92
.48	6.32	1.80	Metering same as EM 92

* No df included.

displacement (345 cubic inch) engine, tested at high (5000 pounds IW), the technical staff concludes that this technology is also transferrable to smaller displacement engines and lighter vehicles. In fact, the modifications used for the 345 cubic inch engine at high altitude back in 1977, demonstrate levels of emissions for HC and CO at high altitude that are lower than some 1980 MY equivalent models at low altitude conditions.

Jaguar-Rover-Triumph (JRT)

Light Duty Vehicles

Based on the CO waiver application from Jaquar-Rover-Triumph (British Leyland), the assumed engine usage for the 1982 and 1983 model years is:

1. 122 CID CLEFI/3W
2. 215 CID CLEFI/3W/EGR
3. 258 CID CLEFI/3W/AIR
4. 326 CID CLEFI/3W/3W

JRT submitted no high altitude data for any of these engines. They have CO waivers for the 1982 model year for the vehicles using the 215 and 326 cubic inch engines.

Pass/Fail Analysis of the 122 CID Engines

Method 3 was used to analyze the available data for this engine. Data for this engine size were taken from durability vehicles for two engine families, both of which were equipped with the same emission control system and the same engine displacement. The system includes a closed-loop electronic fuel injection system with a three-way catalyst. The extrapolated 4000 mile certification test results were averaged as were the deterioration factors. The deterioration factors representing the lowest dfs were also examined. High-to-low altitude ratios were chosen for an emission control system consisting of closed-loop electronic fuel injection with automatic altitude compensation, and EGR.

No CO waiver was granted for the 122 CID engine, but the predicted 50,000 mile results shown in Table JRT-1 illustrate that in all cases it passes the 0.57 HC, 7.8 CO, 1.0 NOx standards for light duty vehicles.

Table Jaguar-Rover-Triumph-1

JRT LDV

CID	Emission Control System	Cert. 4K Data*			High to Low Altitude Factors			Cert dfs*			Predicted Results			Pass-Fail				Comments
		HC	CO	NOx	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx	HC	CO_{11}**	$CO_{7.8}$	NOx	
122	CLEFI/3W				1.68	2.57	0.74				0.40	7.34	0.45	P	--	P	P	Average dfs (2)
											0.55	7.34	0.45	P	--	P	P	Lowest dfs
215	CLEFI/3W/EGR				1.68	2.57	0.74				0.57	12.32	0.42	P	F	F	P	CO waiver granted Fails low altitude CO standards One vehicle
258	AIR/CLEFI/3W																	No data-method 4 analysis
258	CLEFI/3W				1.68	2.57	0.74				1.02	10.83	0.84	F	--	F	P	One vehicle fails low altitude CO standards
326	CLEFI/3W/3W																	CO waiver granted No data-method 4 analysis

* Not Yet Publicly Released.

** Engines with a CO waiver have a "P" or "F" in this column. Engines without a CO waiver have a "--" in this column.

Pass/Fail Analysis of the 215 CID Engines

As with all the JRT engines, no emission data vehicle test results are available in certification. Durability vehicle data were examined by method 3 for extrapolated 4K certification results and deterioration factors. The control system includes closed-loop electronic fuel injection, a three-way catalyst, and EGR. High-to-low altitude ratios were developed for this system which includes an automatic altitude compensation device.

The 4000 mile extrapolated certification durability emissions fail to meet the 3.4 CO standard. Also, the predicted 50,000 mile results, using the altitude ratios developed from the Nissan data for this particular control system, indicate that this engine fails to meet both the 1982 and 1983 high altitide CO standards. The predicted 50K results for hydrocarbons and NOx meet the standards.

The fuel injection system employed on the 215 CID engine is the Lucas Electronically Controlled Fuel Injection System. Like the Bosch and Lucas/Bosch systems, it is an air flow sensitive, pulsed, port injection system with one injector per engine cylinder. The air/fuel ratio is controlled near stoichiometry by the use of oxygen sensors in the exhaust down pipes [28 at 6.1].

Statements made by Bosch [2 at Annex 5, p. 5] indicated that their existing electronic fuel injection systems are capable of altitude correction up to 8200 feet with the Lambda control system. In light of this information, as explained in the factors section, the 2.57 CO factor for this system, developed from the Nissan data, seems quite conservative. Because the technical staff is not confident that one test point, which indicates that CO emissions will increase by over 250 percent, is indicative of the actual or typical compensating ability of this fuel injection system, the technical staff concludes that a judgement on the 215 CID engine's ability to comply with the proposed high altitude standards can not be made.

Pass/Fail Analysis of the 258 CID Engine

Two engine families are included in this displacement class. Both are equipped with closed-loop electronic fuel injection and three-way catalysts and one engine is equipped with an air pump. Neither engine has received a CO waiver for the 1982 model year.

Very limited data are available for these engines, but JRT stated in a letter [19 at 1] regarding the final rule making on the high altitude standards that,

> We are now at the point where we are confident of meeting a 7.8 gram CO standard at altitude on all but the 215 CID V-8 and the 326 CID V-12 engines. The 215 CID and 326 CID engine families were granted waivers from the statuatory (sic) CO standards for 1981 and 1982.

No data were available for the AIR/CLEFI/3W engine and the one vehicle that had durability data for the CLEFI/3W engine failed to meet the low altitude CO standard. Therefore, a method 4 analysis was performed on the 258 CID engine.

The fuel injection system employed on the 258 CID engine is the Lucas/Bosch electronically controlled, pulsed, port injection system with one injector per cylinder. The primary control parameters sensed are air flow and engine speed [28 at 08.01-1]. Bosch has claimed that their Lambda control systems are self-compensating up to altitudes of 2500 meters (8200 ft.) [2 at Annex 5, p. 5].

Because of the conflicting information on the ability of this fuel injection system to compensate for altitude, the technical staff can not make a judgement on the 258 CID engine's ability to comply with the standard.

Pass/Fail Analysis of the 326 CID Engine

The emission control system for this engine family includes closed-loop electronic fuel injection and two three-way catalysts [5 at 53397].

No data is available to assess the capability of this engine to meet the standards by methods one, two or three. A method 4 analysis was done, but because of conflicting information on the fuel injection system, and the absence of low altitude certification data, EPA concludes that it cannot make a judgement on the ability of the 258 CID engine to meet the standards.

Nissan

Light Duty Vehicles

EPA assumed that Nissan would market the following engines in 1982 and 1983 based on their CO waiver application:

1. 1.2L PAIR/OC/EGR
2. 1.4L PAIR/OC/EGR
3. 1.5L PAIR/OC/EGR
4. 2.0L FB*/CLEFI/EGR
5. 2.8L CLEFI/3W/EGR

Nissan did not have any 4000 mile data with a certification disposition of pass certification for its 1981 emission data vehicles, but did supply high altitude data on three vehicles. The technical staff assumed this was low mileage data for method I analyses. In addition, 1981 certification durability vehicle data were used for method 3 analyses.

Pass/Fail Analysis of the Nissan 1.2L, 1.4L, 1.5L Engines

Nissan's CO waiver request designated the 1.2L, 1.4L, and 1.5L engines as their A-series engines. The EPA technical staff grouped these engines together for this analysis because they are close in engine displacement and are all equipped with a PAIR/OC/EGR control system and an altitude compensated carburetor.

Two different pass/fail analyses were done on the 1.5L engine using methods one and three. Nissan submitted high altitude data, for the 1.5L engine with the above control system, which EPA assumed to be low mileage emission results. Using a method 1 analysis, average and best case 1981 certification durability deterioration factors were applied to this data and the system passed the 1982/83 HC and CO standards but

---

* FB means "fast burn."

failed NOx (see Table Nissan-1). The NOx value did not meet the low altitude standard either, so it appears that at this stage of the development process the system was not calibrated to the 1.0 NOx standard.

Extrapolated average 4K results from two 1.5L vehicles and average and lowest case df's were applied to Nissan's high altitude factors for the PAIR/OC/EGR control system and were used in a method 3 analysis. This data showed predicted results that passed the 1982/83 standards in all cases. A maximum tolerable NOx altitude factor of 1.20 was calculated (see PAIR/OC/EGR altitude factors section for explanation). This represents a sizable cushion for an increase in NOx emissions. EPA concludes that Nissan has the technical capability to meet the 1982/83 standards with the 1.2L, 1.4L, and 1.5L engines.

Pass/Fail Analysis of the Nissan 2.0 L Engine

The emission control system for the 2.0L engine is expected to include FB/CLEFI/3W/EGR. According to Nissan, an altitude compensator, for the fuel injection system, will also be used [8 at 2].

The method 3 analysis for this engine used Nissan data for the altitude factor, although the EPA technical staff is not confident that CO emissions will increase by over 250% as the data indicates. Statements by Jaguar-Rover-Triumph on the Bosch L-Jetronic fuel injection system, Volvo on the K-Jetronic, and Bosch statements on the two systems are not in agreement with the results of the Nissan data. Nevertheless, even using the altitude factors developed from the Nissan data, the predicted results listed in Table Nissan-1 indicate that the 2.0L engine can comply with the high altitude standards.

Pass/Fail Analysis of the 2.8L Engine

This engine is expected to be equipped with a CLEFI/3W/EGR emission control system.

Table Nissan-1

Nissan LDV

CID	Emission Control System	4K Data HC	4K Data CO	4K Data NOx	High to Low Altitude Factors HC	High to Low Altitude Factors CO	High to Low Altitude Factors NOx	Cert dfs* HC	Cert dfs* CO	Cert dfs* NOx	Predicted Results HC	Predicted Results CO	Predicted Results NOx	Pass-Fail HC	Pass-Fail CO_{11}***	Pass-Fail $CO_{7.8}$	Pass-Fail NOx	Comments
1.2L,	PAIR/OC/EGR	*	*	*	1.10	1.76	1.20**				0.33	4.7	1.0	P	--	P	P	Lowest dfs
1.4L, 1.5L											0.35	5.2	1.0	P	--	P	P	Average dfs (2)
1.2L,	PAIR/OC/EGR	0.36	5.1	1.59	Method 1						0.43	5.5	1.6	P	--	P	F	Lowest dfs
1.4L, 1.5L											0.45	6.1	1.6	P	--	P	F	Average dfs (2)
2.0L	FB/CLEFI/3W/EGR	*	*	*	1.68	2.6	0.7				0.42	4.3	0.5	P	--	P	P	One vehicle
2.8L	CLEFI/3W/EGR	0.52	5.4	0.35	Method 1						0.52	6.1	0.4	P	--	P	P	One vehicle

* Not Yet Publicly Released.

** Maximum altitude factor which allows engine to pass.

*** Engines with a CO waiver have a "P" or "F" in this column. Engines without a CO waiver have a "--" in this column.

A method 1 pass/fail analysis was done on this engine. Nissan submitted high altitude data for the 2.8L engine with the above control system. EPA assumed these data to be low mileage emission results. 1981 certification durability deterioration factors from one vehicle were applied to these data and the system passed the 1982/83 standards for all three regulated pollutants (see Table Nissan-1). The predicted results as listed in the table indicate that this engine displays the technical capability to meet these standards.

Nissan

Light Duty Trucks

Based on 1981 certification data, Nissan is expected to market only one light duty gasoline engine for their light duty trucks. The Nissan A engine is expected to be available with emission control system 1. Data from five California emission data vehicles and two durability vehicles were used in a method 2 analysis. The predicted results listed in Table Nissan-2 indicate that engine A easily complies with the proposed standards for HC and CO using either the lowest or average dfs.

NOx altitude factors of 2.79 and 2.73 were used with the lowest dfs and average dfs respectively. Power-to-weight ratios were not available (N/A) for the vehicles from which the factors were developed and, therefore, were not compared to the 1981 certifications LDTs.

Based on the predicted results listed in the table, the technical staff concludes that engine A with emission control system 1 has the ability to meet the proposed standards.

TABLE Nissan-2

NISSAN-LDT

DISP.*	Emission Control System*	HP/ETW RATIOS: Ref. Veh.* (X 10^{-2})	HP/ETW RATIOS: Cert. 4K Veh's.* (X 10^{-2})	HP/ETW RATIOS: LDT to 4K Ref. Veh. (%)	AXLE RATIOS: Ref. Veh.* (X 10^{-2})	AXLE RATIOS: Cert. 4K Veh's.* (X 10^{-2})	AXLE RATIOS: LDT to 4K Ref. Veh. (%)	Cert. 4K Tests* HC CO NOx ---g/mi---	High to Low Altitude Factors* HC CO NOx	Cert. DF's*	Predicted Results HC (g/mi)	Predicted Results CO (g/mi)	Predicted Results NOx (g/mi)	Pass-Fail 1982 HC	Pass-Fail 1982 CO	Pass-Fail 1982 NOx	Pass-Fail 1983 HC	Pass-Fail 1983 CO	Pass-Fail 1983 NOx	Comments
				N/A			N/A													
A	1										0.61	6.1	2.3	P	P	P	P	P	P	Lowest dfs
											0.68	5.5	2.3	P	P	P	P	P	P	Avg dfs (5)

* Not Yet Publicly Released.

** Maximum altitude factor which allows vehicle to pass.

Peugeot

The technical staff assumes that Peugeot will market the following gasoline-fueled vehicle in the USA for the 1982 and 1983 MYs:

Displacemment	System
A	5

Another engine could possibly be used in 1982 and 1983. The technical staff is not certain of Peugeot's marketing plans for engine B. Regardless of Peugeot's plans, the staff could not make a pass/fail determination for engine B due to a lack of data.

For gasoline-fueled engine A with system 5, the technical staff is not cognizant of high-altitude data required to develop factors for use in methods 1, 2, or 3. Method 4 was, therefore, employed to assess the technological capability for this emission control system to comply with the 1982 and 1983 interim high altitude standards.

Using method 4 (which in this case is method 3 except that some engineering judgement was included in the selection of factors), the following predicted results were determined for this engine:

0.38 gpm HC
7.0 gpm CO
0.58 gpm NOx

Since there was no better data available to assess this Peugeot case, the technical staff has determined that Peugeot has the technological capability to comply with the proposed 1982 and 1983 high altitude emission standards.

Toyota

Light-Duty Vehicles

EPA assumed that the following engines would be marketed in 1982 and 1983 based on information provided in Toyota's CO waiver request.

1.	78.7 CID	PAIR/OC/EGR
2.	88.6 CID	PAIR/OC/EGR
3.	108.0 CID	CLAIR*/3W/EGR
4.	134/144.4 CID	CLAIR/3W/EGR
5.	168.4/156.4 CID	CLEFI/3W/EGR

Pass/Fail Analysis of the 78.7 CID Engine

Analysis of this engine was accomplished by the third method for assessing the technical ability to meet the proposed high altitude standards. 1981 certification durability vehicle 4000 mile extrapolated emission results and deterioration factors were utilized. High-to-low altitude factors were incorporated into the analysis for a system equipped with pulse air injection, an oxidation catalyst, exhaust gas recirculation, and an automatic altitude compensating carburetor. As explained in the PAIR/OC/EGR factors section, a NOx factor was not used. The maximum possible NOx ratio for the predicted results to still meet the standard is 1.16 times the low altitude 50K NOx emissions (see Table Toyota-1). This factor represents a sizeable cushion for a NOx increase.

The predicted results for HC and CO are well below the standards for non-waivered engines. Therefore, the EPA technical staff concludes that the 78.7 CID Toyota engine is capable of meeting the 1982 and 1983 high altitude emission standards.

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*CLAIR means "closed loop air injection system".

TABLE TOYOTA - 1

Toyota LDV

CID	EMISSION CONTROL SYSTEM	CERT. 4K Data* HC	CO	NOx	HIGH TO LOW ALTITUDE FACTORS HC	CO	NOx	CERT DF's* HC	CO	NOx	PREDICTED RESULTS HC	CO	NOx	PASS-FAIL HC	CO_{11}**	$CO_{7.8}$	NOx	COMMENTS
73.7	PAIR/OC/EGR				1.70	1.80	1.16***				0.51	4.73	1.00	P	—	P	P	1 durability vehicle
88.6	PAIR/OC/EGR				1.70	1.80	1.22***				0.42	5.57	1.00	P	P	P	P	1 durability vehicle
108.0	CLAIR/3W/EGR				2.23***	2.50***	1.70***				0.57	7.8	1.00	P	--	P	P	Average DFs (2)
					2.23***	2.79***	1.58***				0.57	7.8	1.00					Lowest DFs
144.4	CLAIR/3W/EGR				2.68***	3.63***	1.41***				0.57	7.8	1.00	P	--	P	P	1 durability vehicle
168.4	CLEFI/3W/EGR				1.68	2.57	0.74				0.47	6.94	0.31	P	—	P	P	1 durability vehicle

* Not Yet Publicly Released.

** Engines with a CO waiver have a "P" or "F" in this column. Engines without a CO waiver have a "--" in this column.

*** Maximum altitude factor which allows vehicle to pass.

Pass/Fail Analysis of the 88.6 CID Engine

In the absence of 1981 certification test data from emission data vehicles, method 3, using extrapolated durability data, was employed to predict the technical ability of these engines to meet the proposed high altitude standards. HC and CO high-to-low altitude factors were used for the control system which includes pulse air injection, an oxidation catalyst, EGR, and an altitude compensating carburetor.

Like the 78.7 CID engine, a NOx factor was not used in the evaluation. The maximum possible NOx factor in this case that would still meet the NOx standard is 1.22 times the low altitude 50K result (see Table Toyota-1).

The 50K predicted results for HC and CO are well below the standards especially since this engine has received a CO waiver. The EPA technical staff concludes that the 88.6 CID Toyota engine is capable of meeting the 1982 and 1983 high altitude emission standards.

Pass/Fail Analysis of the 108 CID Engine

As for all the Toyota light duty vehicle engines, 1981 durability data for the 108 CID was evaluated in the absence of emission data vehicle test results. The emission control system includes a closed-loop air injection system (CLAIR) three-way catalyst and EGR with an altitude compensating carburetor. No high-to-low altitude factors were developed for this control system because no data were submitted by Toyota or the other manufacturers. In the absence of these factors the average 4K emissions were multiplied by the average and best case deterioration factors. The high altitude standards for non-waivered engines were then divided by these numbers to determine the maximum possible HC/CO/NOx factors that would still meet these standards. In the case of the average deterioration factors, the altitude factors are 2.23/2.50/1.70 and in the case of the lowest dfs, the numbers are 2.23/2.79/1.58 (see Table Toyota-1). These numbers represent relatively high ratios for all three pollutants. In the judgement of the technical staff, the only ratio that may be troublesome is the average CO value. A factor this high for a control system such as this seems quite unlikely though, especially with a closed-loop air system which should, according to Toyota, effectively compensate for A/F fluctuation and produce a higher conversion efficiency [29 at 8]. The EPA staff concludes that it is technically feasible for Toyota to pass the 1982 and 1983 standards with the 108 cu. in. engine.

Pass/Fail Analysis of the 134/144.4 CID Engines

The 134 and 144.4 CID engines were considered together as they have previously been certified in the same engine family. As with the 108 CID engine, extrapolated 4K emissions and deterioration factors were examined from 1981 certification durability data by method 4 for a closed-loop air injection system, three-way catalyst, and EGR system with an altitude compensating carburetor. Again, since no high-to-low altitude factors were developed for this control system, 4K emissions and deterioration factors were used to determine the maximum possible altitude factors that would still meet the high altitude standards. For HC, CO, and NOx the altitude factors are 2.68/3.63/1.41, respectively (see Table Toyota-1). These ratios are higher than those projected for the 108 CID engine with the same emission control system, especially the CO factor. The predicted CO results for this engine is 32.4% lower than the average predicted CO result for the 108 CID engine. This engine is also equipped with the closed-loop secondary air control system which should compensate for altitude [29 at 8].

EPA therefore, concludes that it is technically feasible for Toyota to meet the 1982 and 1983 high altitude standards with the 134/144.4 CID engine.

Pass/Fail Analysis of the 168.4/156.4 CID Engine

These engines have also been analyzed together as they have previously been certified in the same engine family. The system includes closed-loop electronic fuel injection, three-way catalyst and EGR. The EFI system also includes an altitude compensation device. The factors for this emission control system were developed from data submitted by Nissan [8 at 3] and are listed in Table IV-4. Analysis of the 1981 certification extrapolated 4k durability data and deterioration factors indicates predicted 50K results that pass the 1982 and 1983 high altitude standards (see Table Toyota-1). The design of the EFI system with high altitude compensation, as with manufacturers with similar systems, indicates that Toyota has the technical capability to meet these standards with the 168.4/156.4 CID engine.

Toyota

Light Duty Trucks

EPA assumed that the following engines would be marketed in 1982 and 1983 based on 1981 certification information.

1. A CID system 1

2. B CID system 2

Pass/Fail Analysis of the A LDT Engine

A method four analysis was used to assess this engine's ability to meet the standards. The emission control system judged capable of meeting the standards for this engine is system one. No high-to-low altitude factors were developed for this control system.

Extrapolated 4K emissions and deterioration factors were used to determine the maximum possible high-to-low altitude factors that would still meet the standards. These factors came out to be 11.05 HC, 12.30 CO, 3.50 NOx for 1982, and 5.52 HC, 6.62 CO, 3.50 NOx for 1983. These factors are extremely high and indicate a large margin of safety for meeting the standards in both model years. Based on these results, the technical staff concludes that Toyota has demonstrated the technical capability to meet the standards with the A engine.

Pass/Fail Analysis of the B LDT Engines

Method three was used to assess engine B and emission control system two.

Predicted 50K emission results are well below the standards for both 1982 and 1983. These data indicate that Toyota has the technical capability to meet these standards with the B engine.

Table Toyota-2

Toyota LDT

DISP.*	Emission Control System*	HP/ETW RATIOS: Ref. Veh.* (X 10^{-2})	HP/ETW RATIOS: Cert. 4K Veh's.* (X 10^{-2})	HP/ETW RATIOS: LDT to 4K Ref. Veh. (%)	AXLE RATIOS: Ref. Veh.* (X 10^{-2})	AXLE RATIOS: Cert. 4K Veh's.* (X 10^{-2})	AXLE RATIOS: LDT to 4K Ref. Veh. (%)	Cert. 4K Tests* HC (g/mi)	Cert. 4K Tests* CO (g/mi)	Cert. 4K Tests* NOx (g/mi)	High to Low Altitude Factors HC	High to Low Altitude Factors CO	High to Low Altitude Factors NOx	Cert. dfs	Predicted Results HC (g/mi)	Predicted Results CO (g/mi)	Predicted Results NOx (g/mi)	Pass-Fail HC 2.0	Pass-Fail HC 1.0	Pass-Fail CO_{26}	Pass-Fail CO_{14}	Pass-Fail NOx	Comments
A	1										11.05**	12.30**	3.50**		2.0	26	2.3	P	-	P	-	P	One Vehicle, No Factors Developed for this System
											5.52**	6.62**	3.50**		1.0	14	2.3	-	P	-	P	P	
B	2			-17			+64				*	*	*		0.41	4.66	1.06	P	P	P	P	P	One Vehicle

* Not Yet Publicly Released.

** Maximum Altitude Factors which Allow Vehicle to Pass.

Volkswagen

According to VW's CO waiver application of July 1979, the 97 CID engine was to be fuel injected for 1981 and 1982 if the waiver for their feedback carburetor system were denied. Since the waiver was denied, a method 4 analysis was used to address the issues VW raised in their comments concerning their feedback (Lambda-sond) fuel injection system.

VW currently has a CO waiver application in for their 1.46 L engine. VW stated they would not market this engine if their waiver request was denied [33 at 0.2]. The ability of the 1.46L engine to comply with the standards was not assessed in this analysis because VW has not decided if they will use the 1.46 liter engine.

VW made the following statements regarding their emission control systems and their ability to comply with the proposed high altitude standards for 1982-1983:

> In model year 1982, Volkswagen and Audi will use lambda-control technology on the gasoline fuel injection concepts as well as carburetor concepts. Although the lambda-control system is, in fact, able to compensate for changes in air density, the EPA assumption that 'these emission control systems are designed and calibrated for the full range of altitudes where emission reductions are required' is not absolutely valid for Volkswagen/Audi systems.
>
> The entire control range for lambda-control systems is required to compensate for the lambda-variations in part-load to accurately operate the engine, compensate for variations in production tolerances for fuel metering systems and engine components, as well as the deterioration during the useful life. If the system is forced to compen sate for high altitude enrichment the system is required to operate at its limit and cannot further compensate for the variation stated above. Therefore, additional high altitude corrections become necessary for vehicles to safely comply with the appropriate standards.
>
> Modification of those vehicles which utilize the lambda-control system would require a complete replacement of the electronic control unit and addition of an aneroid device sensing changes in barometric pressure which would trip a micro-switch activating alternate functions in the control unit for high altitude

> operation. This modification is expected to be expensive and cannot be developed in time to apply to the model year vehicle affected by the proposed regulations. Any simpler modification, such as the application of devices external to the control unit which would modify its function would merely shift the entire fuel flow curve characteristics for the system and not expand the range of authority [1 at 6 & 7].

VW's lambda-controlled fuel injection system is the Bosch K-Jetronic fuel injection system. Bosch has made the following statements about their fuel injection systems:

> For both existing systems K- and L-Jetronic altitude compensations have been developed and were partially introduced by some of our customers.
>
> Fig. 7 shows an aneroid acting on the warm-up regulator of the K-Jetronic by modifying the control pressure.
>
> Fig. 8 shows an altitude compensation for the L-Jetronic where an aneroid actuates a potentiometer which is connected to the electronics.
>
> No altitude correction is required with Lambda control. The controlled range is designed such that no error exists for altitudes up to 2,500 meters [8,200 ft.][2 at Annex 5, p. 5].

Bosch's statement that the controlled range on their Lambda-controlled fuel injection systems are "designed such that no error exists for altitudes up to 2,500 meters [8,200 ft.]" contradicts VW's statements that:

> The entire control range for lambda-control systems is required to compensate for the lambda-variations in part-load to accurately operate the engine, compensate for variations in production tolerances for fuel metering systems and engine components, as well as the deterioration during the useful life. If the system is required to operate at its limit and cannot further compensate for the variation stated above. Therefore, additional high altitude corrections become necessary for vehicles to safely comply with the appropriate standards [1 at 6].

VW's statements are placed further into question by Volvo's SAE Paper entitled "Development of the Volvo Lambda-Sond System" from which the following was taken:

> HIGH ALTITUDE PERFORMANCE was evaluated in the Denver region of the USA. Tailpipe CO measurements indicated full compensation from 0 to 12,000 ft altitude.
>
> Results from representative CVS testing:

	HC	CO	NOx
0 m (Volvo/Gothenburg)	0.16	2.15	0.39
ATL, Denver	0.31	2.86	0.32

> The increase in HC, CO was caused by rich A/F during cold start condition and poor performance of the manifold depression limiting bypass valve [3 at 13]."

The Volvo Lambda-Sond system is a Bosch K-Jetronic fuel injection system as is VW's. The Volvo data show that the system met the 1981 low altitude emission standards when tested at high altitude in Denver. It should be noted that these data were published early in 1977.

At the high altitude hearings it was brought up to VW that the Volvo fuel injection system seemed to be similar to the VW system, yet had compensation limits of sufficient range for meeting the low altitude standards of 0.41 HC, 3.4 CO, 1.0 NOx. They were asked to address why it wouldn't be possible to extend the limits of compensation for the VW system, and what would be involved in doing so [4 at 298-309]. In their final written submittal, VW did not provide EPA with any insight as to why their K-Jetronic fuel injection system would not perform as well as the Volvo K-Jetronic fuel injection system at high altitude. Also, VW was asked to provide data on their 1981 and 1982 systems [4 at 297 & 298]. Their response was as follows:

> At this time only a limited amount of data is available which is very preliminary in nature. The limitations result from a restricted high altitude test capacity. As a result of these conditions, Volkswagen has little confidence in the data and feels that the data are statistically insignificant.

> A program of vehicle measurement at altitude is beginning and Volkswagen will attempt to provide data based upon availability [emphasis added][4 at 9].

The preliminary nature of the VW data would not provide sufficient grounds for the EPA technical staff to judge that VW is not technically capable of meeting the standards even if the data had been provided.

Based on the statements and data from Volvo and Bosch (Bosch designed the K-Jetronic fuel injection system) and the absence of data to support VW's assertions, the EPA technical staff's judgement is that VW will be able to comply with the proposed high altitude standards of 0.57 g/mi HC, 7.8 g/mi CO, and 1.0 g/mi NOx with their Lambda-controlled fuel injection system.

VW is not currently using a Lambda-controlled carburetor. In their CO waiver application dated July 1979, VW indicated they were unable to meet the applicable standards at low altitude with the Lambda-controlled carburetor, therefore, this system's capabilities at high altitude were not assessed. Also, VW indicated that the fuel injection system will be available [5 at 53399].

B. Diesel-Fueled Vehicles

Pass/Fail Analysis of Diesel-Fueled Vehicles

Light Duty Vehicles

General Motors, Peugeot, Volkswagen, Merecedes Benz, Volvo, Audi, and International Harvester offer Diesel fueled vehicles in their product mix for light duty vehicle and/or light duty truck applications. The Diesel combustion process tends to produce low HC and CO emissions, and the technical staff's judgement is that the interim high altitude standards should not pose a problem for this category of engines. There were not many comments from the manufacturers concerning this issue. General Motors did comment that:

> For Diesel engines, adjustments have a much smaller effect on HC, CO and NOx compared to gasoline engines, but can reduce exhaust smoke [18 at 1].

In order to assess the ability of Diesel engines to comply with the standards, the technical staff developed high/low altitude emission factors from two distinct sources [9 at Appendix A and Appendix I] and [10 at Task 1]. The data shown in Table Diesel-1 show that HC, CO and NOx emissions are lower for the Mercedes Benz 300D at the high altitude test site. This is explainable since this engine was apparently equipped with an intake-air density compensator. The other high altitude test engine shown in Table Diesel-1 was a prototype GM Oldsmobile Diesel. Comparing the altitude factors for the Oldsmobile in Table Diesel-1 to factors for the high-to-low altitude standards (high ÷ low altitude standard) of 1.89 HC, 2.3 CO, and 1.0 NOx, indicate that Diesel LDVs can comply with the proposed standards without the need for adjustments.

Table Diesel-1

Average Emission
Data from EPA Low Altitude
Test Site Compared to
High Altitude Test Site
[9 at Appendices A and I]

Mercedes Benz VIN-W 123 - 3000D - C791

	HC	CO	NOx	Comments
Lo Alt	0.315	1.25	1.67	EPA-AA
Hi Alt	0.310	1.17	1.54	ATL
Hi/Lo Alt. Factor	(0.98)	(0.94)	(0.92)	

GM-Olds Diesel VIN 3W69N8M105364

	HC	CO	NOx	Comments
Lo Alt	0.510	1.45	1.78	EPA-AA
Hi Alt	0.669	1.76	1.42	GM-Denver
Hi/Lo Alt. Factor	(1.31)	(1.21)	(0.79)	

Other FTP data, more recently developed, for five Diesel LDVs tested at both EPA (for low altitude environment) and at the Automotive Testing Laboratory (ATL) at Aurora, Colorado (5480 feet), are shown in Table Diesel-2. These tests provide the following average high/low altitude emission factors:

HC - 2.27
CO - 1.85
NOx - 1.02

These factors show some upward pressure on HC emissions and negligible effect on NOx emissions. There is also an effect on CO. However, the CO factor of 1.85 is off-set by the higher standard of 7.8 g/mi at high altitude, which is calculated to be 2.3 times the low altitude standard of 3.4 g/mi. Those LDV Diesels certifying (low altitude) at 0.25 g/mi HC or below should comply with the interim high altitude standards. Otherwise, aneroids, other fuel limiting devices, fuel rack adjustments, or injection timing modification options are available to the manufacturers.

In order to test this assumption that Diesel LDVs can comply with the interim high altitude standards for 1982 and 1983, with only minor adjustments, the technical staff applied the more conservative high/low altitude factors of 2.27 HC, 1.85 CO, and 1.02 NOx to low altitude 1980 4K certification, average test results [32 at LDVs] on the GMC, Mercedes, Peugeot, VW, Audi, and Volvo. The predicted results including dfs, are listed below:

	GMC	Mercedes (49 States)		Peugeot		VW	Audi	Volvo
	(NA)	(NA)	(TC)	(NA)	(TC)*	(NA)	(NA)	(NA)
HC	0.71	0.72	0.54	0.72	0.49	0.82	0.91	0.66
CO	3.86	1.98	1.98	2.4	2.5	2.22	2.40	2.53
NOx	1.68	1.50	1.49	1.46	1.0	1.27	1.73	1.70

*4K certification value interpolated from 1981 durability car data as in method 3.

Other FTP data, more recently developed, for five Diesel LDVs tested at both EPA (for low altitude environment) and at the Automotive Testing Laboratory (ATL) at Aurora, Colorado (5480 feet), are shown in Table Diesel-2. These tests provide the following average high/low altitude emission factors:

HC - 2.27
CO - 1.85
NOx - 1.02

These factors show some upward pressure on HC emissions and negligible effect on NOx emissions. There is also an effect on CO. However, the CO factor of 1.85 is off-set by the higher standard of 7.8 g/mi at high altitude, which is calculated to be 2.3 times the low altitude standard of 3.4 g/mi. Those LDV Diesels certifying (low altitude) at 0.25 g/mi HC or below should comply with the interim high altitude standards. Otherwise, aneroids, other fuel limiting devices, fuel rack adjustments, or injection timing modification options are available to the manufacturers.

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	GMC	Mercedes (49 States)		Peugeot		VW	Audi	Volvo
	(NA)	(NA)	(TC)	(NA)	(TC)*	(NA)	(NA)	(NA)
HC	0.71	0.72	0.54	0.72	0.49	0.82	0.91	0.66
CO	3.86	1.98	1.98	2.4	2.5	2.22	2.40	2.53
NOx	1.68	1.50	1.49	1.46	1.0	1.27	1.73	1.70

*4K certification value interpolated from 1981 durability car data as in method 3.

Table Diesel-2

High to Low Altitude Emission Factors Developed From 5 Diesel LDVs Tested at EPA (Ann Arbor, MI) and Again at ATL (Aurora, CO) - grams per mile [10 at Task 1]

Comments	Vehicle	VIN	HC	CO	NOx	Particulate	#Tests
EPA (Lo)	Oldsmobile	3R47P7M	0.386	1.49	1.67	1.1	2 FTP
ATL (Hi)	" "	" "	0.966	2.57	1.57	1.8	2 FTP
Hi/Lo Alt. Factor:			(2.50)	(1.72)	(0.94)	(1.6)	
EPA (Lo)	Oldsmobile	3R47P9M	0.678	1.50	1.44	0.8	2 FTP
ATL (Hi)	" "	" "	1.387	2.206	1.29	1.0	3 FTP
Hi/Lo Alt. Factor:			(2.04)	(1.47)	(0.90)	(1.3)	
EPA (Lo)	V-W Rabbit	17A0815408	0.217	0.78	1.05	0.26	2 FTP
ATL (Hi)	" "	" "	0.588	1.78	1.087	0.37	5 FTP
Hi/Lo Alt. Factor:			(2.71)	(2.28)	(1.04)	(1.4)	
EPA (Lo)	Peugeot	504D90	3.86	3.84	0.94	0.90	2 FTP
ATL (Hi)	" "	" "	6.74	8.88	0.98	2.43	2 FTP
Hi/Lo Alt. Factor:			(1.75)	(2.31)	(1.04)	2.7	
EPA (Lo)	Mercedes	123123120	0.250	0.67	1.30	0.4	3 FTP
ATL (Hi)	" "	" "	0.588	1.04	1.531	0.5	1 FTP
Hi/Lo Alt. Factor:			(2.35)	(1.55)	(1.18)	(1.2)	

Average High/Low Altitude Emission Factor

HC - 2.27

CO - 1.87

NOx - 1.02

Part. - 1.64

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* 34 tests

These results confirm that there could be some upward pressure on HC from Diesel LDVs at high altitude, and that some minor injection timing or maximum fuel adjustments may be required to meet the high altitude standard of 0.57 g/mi. The conservative high/low altitude factor of 1.02 NOx indicates that the manufacturers that certify at low altitude should also conform to high altitude standards. The higher NOx values shown here are to be expected since the NOx standard for 1980 MY vehicles was 2.0 g/mi. For the interim period of 1981 to 1984, Section 202(b)(6)(B) of the Act provides that the Administrator may waive the 1.0 g/mi NOx standard to a level not to exceed 1.5 g/mi upon petition of a manufacturer.

Light Duty Trucks

With respect to the LDT standards for 1982 and 1983, Nissan, who has supplied Diesel engines to International Harvester, provided the following statement [8 at 2]:

> Because the amount of inlet air is reduced at high altitude and excessive air cannot be obtained, an altitude compensator (aneroid type compensator) will be required for the fuel injection system at WOR operation. Furthermore, our simulation test data indicates that HC and CO emissions are likely to increase with altitude even at partial load operation. (The HC and CO emissions during FTP increases 2.2 and 1.4 times repectively.) Therefore, in order to control HC and CO emissions at high altitude, it is considered that using only a compensator is not enough, and recalibration of injection timing and EGR will be necessary.

International Harvester has used a turbocharged engine for LDT applications. This engine does have the capability to provide excess air, and the statement by Nissan that "excess air cannot be obtained", does not apply. Furthermore, it is currently accepted practice to install aneroid controls on turbocharged engines for the sole purpose of preventing excess smoke, during acceleration modes. This aneroid could also automatically correct the maximum fuel setting for high altitude conditions.

Nissan, in their submission, considered emission factors of 2.2 and 1.4 for HC and CO, respectively, for high altitude. The EPA technical staff used the more conserative LDV factors of 2.27 and 1.85 for HC and CO in establishing whether this engine would comply with the high altitude standards. Application of these factors to 1980 MY certification test results provided the following predicted results:

0.95 g/mi HC ('83 high altitude standard is 1.0 g/mi HC)
3.51 g/mi CO ('83 high altitude standard is 14.0 g/mi CO)
1.53 g/mi NOx ('83 high altitude standard is 2.3 g/mi NOx)

The technical staff assumes that the same basic Diesel emission control systems used in the 1980 MY will also apply to the 1982 and 1983 MY GMC and VW LDTs. The conservative high/low altitude factors developed for the LDVs were applied to both the GMC and VW LDTs with the following predicted results:

GMC	VW
2.0 g/mi HC	0.73 g/mi HC
4.01 g/mi CO	1.85 g/mi CO
2.14 g/mi NOx	2.18 g/mi NOx

Both the VW Diesel and the Nissan 198TC Diesel, as used by International Harvester, are considered by the technical staff to be capable of meeting the high altitude standards for the 1982 and 1983 model years. Because of upward pressure on HC, the GMC trucks will probably require modifications which may include adjustments of injection timing or the maximum fuel setting in order to comply with 1983 MY standards.

It is the determination of the technical staff, that both light duty vehicles and light duty trucks powered by Diesel engines can comply with the high altitude standards with minor adjustments or, effectively, by addition of aneroid type controls. Particulate emissions were not considered in this determination, but preliminary data on the five LDVs reported in Table Diesel-2 indicate that total particulate emissions may be adversly affected by high altitude operation*. About a 64% increase over low altitude values was noted. For those manufacturers that may have a problem meeting a 0.6 g/mi particulate standard for the 1982 and 1983 model years at low altitude, use of an aneroid control or other advanced technology may be the preferred strategy. This would allow the manufacturers to gain field testing experience in limited volume with advanced controls in anticipation of the tighter particulate standard, 0.2 g/mi, in the 1985 model year.

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*A high altitude particulate standard has not been established for the 1982-1983 model years [35 at 1450].

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