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Final Technical Report
on
Air Conditioning
for the
Federal Test Procedure Revisions
Notice of Proposed Rulemaking

January 31, 1995

U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Mobile Sources

Abstract

This technical report documents the need for additions to the Federal Test Procedure for tailpipe emissions (FTP) to better represent air conditioning (A/C) operation. The first section provides background information and describes how air conditioning is currently represented on the FTP and discusses Agency concerns with the current methodology. Section two presents the results of numerous test programs conducted by the Agency and by manufacturers to investigate and quantify the impact on vehicle emissions of A/C operation. The third section discusses the options for controlling A/C emissions, including a discussion of causes of emission increases, potential control strategies, and the appropriate level of control. Section four discusses the feasibility of emission control, and the last section presents test procedures for testing A/C-on emissions.

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Section 1: Need for Controlling Emissions from A/C Operation

1.1 History/Description of Current A/C Simulation Method

The LA4 driving cycle has formed the basis of the Federal Test Procedure since the 1972 model year. Recognizing that the LA4 cycle itself did not adequately represent the additional load that an air conditioner (A/C) can place on an engine, EPA included regulatory language, effective in the 1972 model year, that specifically addressed this issue. This language required that the dynamometer road-load horsepower be increased by ten percent, to a maximum of 1.4 horsepower, and applied to emission and fuel economy tests on any engine/system combination where it is expected that more than 33 percent of the vehicles will be equipped with an A/C system.[1] This method remains the current regulatory requirement for today's vehicles.

1.2 Concerns with Current A/C Simulation

1.2.1 Representation of A/C Load During Idles

Approximately 19 percent of the LA4 is spent at idle, and Agency driving survey data indicates that approximately 21% of driving time is spent at idle, but the current dynamometer load adjustment method is incapable of applying an additional load at idle. In reality, the A/C system can add approximately 2 horsepower (Hp) to the engine load when a vehicle is at idle.[2]

1.2.2 Accuracy of A/C Load Representation

The current A/C simulation method does not accurately represent the magnitude of true A/C loads on an engine. A typical 4000 pound passenger car might require a dynamometer road-load horsepower setting of 9 Hp (A/C turned off), and

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40 CFR § 86.129-80 (b) (3).

"Concerning Automotive Air Conditioning," a lecture presented to the Environmental Protection Agency by Dr. Ramesh K. Shah, Harrison Radiator Division, General Motors Corporation, May 31, 1994. Available in public docket for review.

therefore the adjustment to account for A/C operation would be less than 1 Hp using the current 10 percent adjustment. In reality, the engine load on such a vehicle with the A/C operating might approach 15 Hp, which, if one assumes losses between the engine and the road of 20 percent, translates to a dynamometer load of 12 Hp. The increase in dynamometer load with the A/C actually operating is therefore 3 Hp in this hypothetical case, more than three times the load that the current simulation would apply. Under severe conditions of temperature and humidity the actual additional load on an engine due to A/C operation could be in excess of 9 Hp.[3] In addition, the current method applies a load that diminishes as speed diminishes, while in reality the A/C load on the engine tends to be a greater proportion of the total load at lower speeds and a smaller proportion as speed increases.

1.2.3 Inequities in A/C Loading

Different vehicles have different road-load horsepower settings for the dynamometer. A full-sized passenger car could have a base road-load horsepower of 10 Hp, while a compact passenger car could have a setting of 5 Hp. Because of this a ten percent increase in these base settings will cause the vehicles to have different representations of A/C load, whether or not they use the same A/C system.

Section 2: Emission Impact of A/C Operation

The Agency conducted three test programs and participated cooperatively with AIAM and AAMA in an additional test program during late 1993 and early 1994 with the purpose of assessing in-use emissions due to air conditioner operation. The first two programs, commencing in August 1993, suggested that a potentially large shortfall of the current FTP with respect to A/C operation might exist, precipitating additional testing and analyses. A third Agency program essentially repeated one of the earlier programs but collected second-by-second data to allow more detailed analyses of the emissions impacts. The fourth program, run in cooperation with and funded by a consortium of vehicle

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manufacturers, also collected second-by-second data, but made these measurements in a test facility that allowed an accurate simulation of real-world environmental conditions.

2.1 EPA Test Programs

One of the August 1993 programs attempted to directly estimate the A/C emission impact by testing thirty-one vehicles on the conventional FTP under two scenarios: 1) with the A/C off and the standard ten percent dynamometer road-load horsepower adjustment applied, and 2) with the A/C operating and the ten percent adjustment not applied. This testing was carried out on a conventional Clayton twin-roll dynamometer in a standard Agency test cell at a standard ambient temperature of 75°F. The Agency found that tests run with the A/C operating produced more emissions (with a corresponding decrease in fuel economy) than tests run with the ten percent dynamometer adjustment, confirming that the ten percent loading method significantly underrepresents the actual load of the air conditioner on the engine.[4] On the hot stabilized portion of the FTP the average increases observed with the A/C actually engaged were 0.019 g/mi for THC, 0.3 g/mi for CO, and 0.155 g/mi for NOx. These increases are simply an estimate of the additional amount modern technology vehicles actually emit in-use with the air conditioner engaged, compared to the emission results on the conventional FTP. Because both of the scenarios were tested at 75°F, it is likely that these data understate the actual in-use emission increase. Typical high ozone situations occur with an average temperature of 95°F[5]; these higher temperatures would be expected to impose a greater load on the A/C system, with a correspondingly greater emissions impact. Data from this test program is shown in Appendix A.

The second August 1993 program went beyond the current FTP by testing three vehicles on the three representative cycles

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In fact, the Agency believes that the effect on emission values of the additional ten percent dynamometer road-load horsepower is negligible and unobservable within the range of current test-to-test variability.

Agency ozone and meteorological data on the 15 highest ozone occurrences for 44 cities from 1988-1992.

(REP05, ST01, Remnant)[6] as well as over the LA4, again with A/C on and A/C off test scenarios. The vehicles were tested on a large-roll electric dynamometer, and at least two sets of data were collected on each cycle in each A/C configuration. No change was made to the dynamometer road-load settings between A/C off and A/C on tests. All of the tests were conducted in a fully warmed up condition. These tests offered the first data available to the Agency demonstrating the impact of the A/C over the high speed and high acceleration REP05 and the more FTP-like ST01 and Remnant driving cycles. The emission test results of the ST01, Remnant, and REP05 cycles were weighed together (using the in-use weighting factors determined from the Agency's in-use driving survey, i.e. 24%, 48%, and 28%, respectively) to represent an overall in-use impact based on the Agency's representative driving cycles. As in the program described above, results from this testing demonstrated an overall increase in actual emissions with the A/C operating. THC increased about 24% (0.025 g/mi), CO increased about 56% (2.3 g/mi), and NOx increased by about 76% (0.21 g/mi). The Agency noted that about 95% of the in-use weighted NOx increase occurred on the ST01 and Remnant cycles, with the remainder coming from the REP05 cycle; only half of the THC and CO increases occured on the combined ST01 and Remnant cycles, with the other half on the REP05 cycle. The Agency believes that the increases seen in THC and CO were consistent with the increased load imposed by actual air conditioning operation; the larger increase in CO relative to THC is consistent with the fact that CO is more sensitive to load than THC. However, the magnitude of the NOx increase in both of these test programs was much larger than expected and caused the Agency to focus further research and analysis on the effects of A/C operation on NOx emissions. The bag emissions data from this program are presented in Appendix B.

To investigate this large NOx increase further, EPA conducted a third test program. It was very similar to the second but was designed to collect second-by-second emissions and vehicle operating data, again on three vehicles (two of which were carried over from the previous test program). The purpose of this program was to help identify the causes and sources of the large NOx increase, particularly with respect to the moderate

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For the purposes of testing, the ST01 and Remnant cycles were combined into one driving cycle, referred to as REM01. For a detailed discussion of the development of these cycles see the US06/Aggressive Driving Technical Report.

driving of the Remnant, ST01, and LA4 cycles. Data was also collected on the REP05 driving cycle. The second-by-second data allowed the Agency to closely analyze the driving modes and vehicle operating parameters that contributed most significantly to the A/C-on emission increases. In addition to the emissions and vehicle data collected on a second-by-second basis, the Agency also collected second-by-second data on the A/C compressor clutch operation, the compressor head pressure, and the temperature of the air entering the condenser, as well as several other parameters. The second-by-second emissions were used to analyze the impact of A/C operation in four driving modes (idle, acceleration, cruise, deceleration). Overall, the results compared favorably with the results observed in the previous 3-car program; the impact of A/C operation on HC was typically negligable, except for a minor (5%) average increase on the REP05 cycle; the impact on CO was also minor or non-existant on the REM01 and LA-4 cycles, but showed an average increase of 48% on REP05 (97% of which occured on accelerations, indicating likely commanded enrichment impacts); and NOx increased by 69% and 77% on the LA-4 and REM01 cycles respectively, but on REP05 the increase averaged only 20%. The Agency found that on these three vehicles the significant impacts were occuring on idles and accelerations. Emissions increased on idles an average of 536% and 788% on the LA-4 and REM01, respectively. On both of these cycles, the combination of idles and accelerations accounted for more than 80 percent of the total observed NOx increase (each mode accounting for more than 40%). On the REP05 cycle, most of the NOx increase occured during accelerations and cruises, but the overall percent increases in each mode were typically lower. Data from this program is contained in Appendix C.

2.2 Manufacturer Test Programs

Following the above test programs, the Agency was willing to conclude that air conditioner operation represents a significant source of in-use emissions that is not reflected on the current FTP, and that the in-use emissions impact was reasonably well-characterized by the EPA test data. All of the data collected by the Agency test programs, as well as the resulting analyses, were shared with the vehicle manufacturers, who typically remained less convinced by the Agency's data. In particular, the Agency's programs were criticized for providing less than adequate air flow to the air conditioner condensor, resulting in loads on the A/C system that were overstated, and therefore also resulting in emission increases that were overstated. The Agency agreed that the test conditions were not fully representative of "real-world" conditions and that similar data collected under more realistic conditions would add significantly to the understanding of the issue. Manufacturers agreed to support such a test program, described in detail below.

The test program discussed in this section was made possible through a cooperative effort with various individual automobile manufacturers and the American Automobile Manufacturers Association (AAMA) and Association of International Automobile Manufacturers (AIAM) trade organizations. Funding for the test program came through the manufacturers and trade organizations and vehicles were provided by the manufacturers. The testing program was administered by the EPA/AAMA/AIAM Ad Hoc Committee on Air Conditioning under the AAMA/AIAM Revised FTP Oversight Committee.

To model the real world in a test cell it was necessary to identify and simulate the parameters which affect air conditioner performance. The Agency identified the following principle parameters: ambient temperature, sun load, humidity, cooling (from the vehicle moving through the air), interior temperature of the vehicle, and pavement temperature. Other factors such as the color of the car, pavement type, cloud cover, and cross winds all contribute to the impact of these parameters.

The specifications of the environmental testing facility of General Motors' at AC Rochester (ACR) in New York demonstrated an acceptable climate control capability and the required ability to measure emissions results and vehicle operating parameters on a second-by-second basis. General Motors agreed to provide the use of this facility for the test program, which was completed in May, 1994. The ACR facility allows control of the temperature and humidity in the test cell. The wind speed can be matched to vehicle speed through the use of a wind tunnel which provides accurate air flow for the front of the test vehicle. The ACR lab also allows independent control of the pavement temperature and has a bank of heat lamps which can be adjusted to provide luminescent energy equal to a given sun load. The heat lamps are not able to cover the whole car, nor can they provide a given level of radiant energy at all vertical heights (the hood will be at one level and the roof will be subject to a higher level). However, by placing the heat lamps over the base of the center of the windshield and setting the luminescent level at the joining of the hood with the windshield, the sun load can be accurately represented on the critical portions of the vehicle.

The following sections detail how the Agency defined the conditions to simulate at ACR and discuss the results and data analyses. Appendix D contains the detailed test plan and the resulting bag emissions data for the ACR testing program.

2.2.1 Selection of Environmental Conditions for Simulation at ACR

The Agency placed its emphasis on controlling air conditioning emissions during ozone exceedance days. Clearly, such days are of primary concern from an emissions standpoint. In addition, ozone exceedances tend to occur during higher temperatures when air conditioner usage is virtually certain and air conditioning performance will be near its design limits. The EPA reasoned that if acceptable emission control could be secured during these typically high-temperature days, similar control could be expected on cooler days when air conditioning is less used and the air conditioning systems are under less load.

One of the objectives of the Agency's investigation into FTP revisions is to implement emission test procedure changes that will result in a reduction in high ozone occurrences.[7] Therefore, the ambient test conditions selected for use in the ACR test program were determined from the observed ambient conditions that existed during known high ozone occurrences. In terms of ambient air temperature, this is the same rationale that was used to determine the 96°F temperature requirement for the 1996 model year evaporative emission running loss regulations. The ambient test conditions identified that directly affect the work performed by a vehicle's A/C system are air temperature, air humidity, pavement temperature, solar heat load, the vehicle's interior temperature, and vehicle cooling from airflow through the engine compartment. The ambient conditions documented in the following discussion were used to determine the effect of A/C operation on exhaust emissions during the industry testing program at the ACR environmental facility.

2.2.1.1 Ambient Air Temperature

Data provided by the EPA Office of Air Quality Planning and Standards were evaluated to determine appropriate levels of ambient temperature and relative humidity. These data provide the climatic conditions for the 15 highest values of one-hour maximum ozone levels over a period of five years (1988-1992) for 44 cities (Consolidated Metropolitan Statistical Areas) where the ozone levels have been historically high. The type of

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An ozone exceedance is obtained whenever the ozone levels exceed the National Ambient Air Quality Standard of 120 parts per billion (ppb) for one hour.

information contained in the database are: city name, daily maximum 1-hour ozone in parts per billion, ambient surface temperature, wind speed, relative humidity, cloud cover, and mixing height.

Table 1 is a summary of the maximum daily ambient temperature by city for the 15 highest ozone levels in the years 1988 through 1992. The average ambient air temperature for all cities and all years is 90°F. The percent of cities with a five year average temperature above 95°F for these high ozone days is 13.6%. Given the total number of yearly sets of data that these 44 cities represent (5x44=220), 19.1% have an average temperature above 95°F.

Table 2 shows ambient temperature data on the basis of the number of daily occurrences where the temperature was greater than 95°F. These data indicate that two cities had no high ozone occurrences in the years 1988 through 1992 where the daily maximum ambient temperature was greater than 95°F. The percent of daily maximum observed temperatures for each city that are greater than 95°F range from 96.0% for Phoenix, Arizona to 0% for Bridgeport-Milford, Connecticut and Muskegon, Michigan (total number of high ozone occurrences for a city is 5 years x 15 occurrences/year = 75). The last column of Table 2 is the average temperature, by city, of those observed maximum daily temperatures that were greater than 95°F.

Figure 1 shows cumulative frequency distributions of daily maximum ambient temperature for all high ozone occurrences and only those occurrences exceeding the ozone standard (a subset of all high ozone occurrences in the database). The cumulative curve based on all the high ozone occurrences shows that 73.8% are less than or equal to 95°F, and conversely that 26.2% are greater than or equal to 95°F. The cumulative curve based only on those occurrences exceeding the ozone standard shows 68.6% $\leq$ 95°F, and conversely 31.4% $\geq$ 95°F.

Table 3 is a summary of the data used for the graphical results of Figure 1. Notice how quickly the cumulative percentage values of Table 3 decrease with a decrease in ambient temperature from 95°F to 90°F. For the database of all high ozone occurrences this results in a reduction of 27.0% (from 73.8% to 46.8%); and for the ozone standard exceedance subset this results in a reduction of 28.7% (from 68.6% to 39.9%).

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INSERT FIGURE 1 - NOT AVAILABLE IN THIS ELECTRONIC VERSION

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The analysis of meteorological data used to evaluate the 95°F specified for the 1996 model year evaporative running loss test temperature was based on ambient temperatures observed on ozone standard exceedance days. In that analysis, the EPA found that the average of the top 10% of the temperatures for each of the cities analyzed was 96°F. A similar analysis of the meteorological data for ozone standard exceedances used for the current A/C study results in an average temperature of 95°F. Based on these analyses, the EPA specified 95°F for use in the ACR test program.

2.2.1.2 Relative Humidity

Table 4 is a summary of the daily average relative humidity values corresponding to the observed ambient temperatures shown in Table 1 for the 15 highest ozone days. The average relative humidity for all cities and all years is 45.2%, but this occurs at an average temperature of 90°F. The important consideration is specification of a representative relative humidity for an air temperature of 95°F. It is important to ensure that a specified relative humidity can be expected to exist at the specified air temperature.

Figure 2 shows the relationship of the average relative humidity values of Table 4 with the average high ozone temperature values of Table 1 for all 44 cities. The regression line fit to these data yields a value of 37.2% relative humidity at an air temperature of 95°F. Based on this analysis, the EPA selected a relative humidity of 40% for the A/C testing program conducted at the ACR environmental testing facility.

INSERT TABLE 4 - NOT AVAILABLE IN THIS ELECTRONIC VERSION

INSERT FIGURE 2 - NOT AVAILABLE IN THIS ELECTRONIC VERSION

2.2.1.3 Pavement Temperature

A simulated pavement temperature of 135°F (40°F higher than the specified 95°F ambient air temperature) was selected as the target pavement temperature for the ACR test program. The selection of 135°F pavement temperature was the result of two factors: first, the manufacturers consider a 40°F differential between ambient and pavement temperatures as a reasonable estimate of the effect of high-intensity solar load for air conditioning development testing, and second, 135°F was the maximum simulated pavement temperature possible at the ACR facility. A degree of uncertainty in the pavement temperature determination was acceptable because the Agency believes that pavement temperature contributes significantly less to air conditioning cooling load than ambient air temperature.

Subsequent to the ACR test program General Motors provided pavement temperature data as a function of ambient temperatures for the daylight hours during the months of June through August. A regression line fit to a plot of this data is shown in Figure 3. These data and regression line indicate that an ambient temperature of 103°F is required to obtain an average 40°F differential above the ambient temperature. Based on these data the Agency concluded that 135°F was a reasonable value to simulate in the ACR test program.

insert figure 3 -- Figure 3 is not available in this electronic copy. See the Public Docket A-92-64 for a complete version of this document, including this figure.

2.2.1.4 Solar Load

Figures 4 and 5 are plots showing the measured solar load (watts/meter^2 on a flat surface) as a function of the time of day for the month of August 1993 at the University of California Davis and Riverside, California. These data, provided by General Motors, were obtained from a database maintained by the state of California. Both of these plots show that a solar load of at least 850 W/m^2 existed for three to four hours each day for the vast majority of the days in August, 1993. Ford presented an analysis using known figures for total solar flux and global averages for reflectance and absorbtion, suggesting that 711 Watts/meter^2 is a more appropriate figure. Their analysis clearly results in an accurate estimate of the average on a global basis, but the Agency was seeking a value that would cover a greater percentile of experience than that represented by the average. Toyota shared some data collected mostly in Phoenix, Arizona and Southern California that identified 900 Watts/meter^2 as an average mid-day maximum (occuring at solar noon) during the months of July and August. Believing that Phoenix may be unrepresentative, the Agency adjusted this figure for the difference in cloud cover between Phoenix ozone non-attainment days and the average cloud cover for all ozone non-attainmment days, which resulted in 843 Watts/meter^2. The Agency also pursued this issue in the solar energy literature, and found that "...the peak clear day insolation received in most sections of the U.S. would...reach a value of about 300 BTU/ft^2/day."[8] This is equivalent to 945 Watts/meter^2. Given that this figure represents a clear day, the Agency chose to adjust this for some representative level of cloud cover and reflectance, an analysis that resulted in a figure of 866 Watts/meter^2. Based on these data and research the solar load used for the ACR A/C test program was set to 850 Watts/meter^2. This solar loading was simulated with banks of lights located above the test vehicles.

Cheremisinoff, Paul N., and Thomas C. Regino. Principles and Applications of Solar Energy, Ann Arbor Science Publishers, Inc., 1979.

insert figure 4 -- Figure 4 is not available in this electronic copy. See the Public Docket A-92-64 for a complete version of this document, including this figure.

insert figure 5 -- Figure 5 is not available in this electronic copy. See the Public Docket A-92-64 for a complete version of this document, including this figure.

2.2.1.5 Vehicle Interior Temperature

A vehicle's stabilized interior temperature at an ambient exterior air temperature of 95°F will increase as a function of the time of exposure to a solar heat load. Several SAE papers involving A/C test performance programs specify 140-149°F as the desired interior test temperature at the start of test.[9],[10],[11] For the ACR test program, 130°F at the headrest level was selected as a desired interior air test temperature. In the actual ACR test program, however, A/C testing was initiated at the end of an hour of exposure to the ACR ambient conditions even if the interior temperature had not quite reached 130°F.

2.2.1.6 Vehicle Cooling

Air flow cooling supplied to the vehicle for the ACR test program was proportional to the vehicle speed on the dynamometer. This is routinely the procedure in an environmental test facility, and important to the objectives of the test program because of the need to supply the most "real-world" air flow conditions possible to the air conditioning system.

Table 5: Summary of Environmental Parameters for ACR Test Program

Environmental Parameter	Specification for ACR Test Program

R. El-Bourini, et all, "Performance Evaluation of an Automotive Air Conditioner with Expansion Valve Control Using CFC-12 and HFC-134a Refrigerants". SAE Technical Paper Series 910218.

David J. Bateman, "Performance Comparison of HFC-134a and CFC-12 in an Automotive Air Conditioning System". SAE Technical Paper Series 890305.

R. El-Bourini, et al, "Automotive Air Conditioning System Performance with HFC-134a Refrigerant". SAE Technical Paper Series 900214.

Air temperature	95°F
Relative humidity	40%
Pavement temperature	135°F
Solar load	850 Watts/meter^2
Interior temperature	130°F
Vehicle cooling	Air flow proportional to vehicle speed

2.2.2 ACR Test Procedure Issues

2.2.2.1 A/C Operation and Settings

It was also necessary to decide how to adjust the air conditioner during the testing. It was the Agency's goal to match actual customer usage patterns in use during the climate conditions selected. However, the vehicle occupants have a wide range of control over the air conditioner settings, and can typically choose between two to four air conditioning modes, the use of recirculation versus fresh air modes, a temperature setting on a slide bar, and between three or four fan settings. In addition, some vehicles have automatic climate controls where the driver chooses a control temperature and the rest is done automatically. At the time, the Agency had no available data describing how drivers select the A/C settings, and as a consequence the setting used are based on little more than expectations and common sense.

Based on input from manufacturers and following a try-out test at ACR, the decision was made to set the A/C mode switch on "max" and the airflow (if separate) to "recirculation" and to use the fan speed alone to modulate the amount of air conditioning. A nominal procedure was established to switch the fan speed (see Appendix D), but switch points could be changed during the first test based on driver preferences. The second test would be run following the same procedure as developed during the first test.

2.2.2.2 Measuring Modal Emissions and Operating Parameters

To understand how and where the emissions occurred during the test the manufacturers measured modal second-by-second emissions in addition to bagged emissions data. Engine-out emissions and tail-pipe emissions were both recorded. Second-by-second operating parameters of the engine were also recorded to evaluate how the vehicle was operating during the cycles. The vehicle parameters measured are listed in Appendix D.

2.2.2.3 Driving Cycles for ACR Test Program

As discussed in Section 2.1, the data collected by the Agency showed that lower speed tests resulted in higher emissions increases due to running the A/C. However, to verify this conclusion the Agency wanted to run a full range of tests that represented most modes of in-use driving. The test cycles chosen for this program were the FTP cycle, ST01, REP05, and a range of steady state conditions.

2.2.2.4 Vehicle Selection for ACR Test Program

The goal in choosing the test vehicles was to represent a wide range of vehicle designs and applications. In selecting the vehicles EPA considered the engine power, vehicle type (car, truck), air conditioning design (manual versus climate control system), and size of the vehicle. The Agency limited the selection to vehicles with HFC-134a refrigerant A/C systems and those meeting Federal Tier 1 or California TLEV emission standards. The vehicles were supplied by the manufacturers and final choices were based on vehicle availability. A list of the vehicles which were involved in the testing program is contained in Appendix D. Data from the Chrysler minivan became suspect and was subsequently discarded from the analyses.

2.2.3 Results of ACR Test Program

The results of the ACR test program are summarized below. Detailed data from the ACR testing program are contained in Appendix D.

The ACR data confirmed the earlier data which showed a significant increase in NOx emissions during FTP testing with the A/C running. NOx emissions averaged 0.214 g/mi without the A/C and nearly doubled to 0.411 g/mi with the A/C running. The difference between A/C on and A/C off was 0.197 g/mi on the FTP. Note that these results are for the entire FTP, including the cold start driving of Bag 1. The impacts of the cold start can be separated by looking at a composite of the hot stabilized driving in Bags 2 and 3, reported in the third row of the table. Bag 1 results are also reported separately. On a Bag 2 and 3 composite NOx increases from an average of 0.164 g/mi with the A/C off to an average of 0.349 g/mi with the A/C on, more than doubling. Table 6 summarizes the average emissions and percent differences ((A/C minus Non-A/C)/ Non-A/C) for the cycles measured. The bag results from the ACR test program showed that the Bag 2 and Bag 3 portions provided more control than the Bag 1 for NOx and HC emissions. However there was a CO increase in Bag 1 emissions which did not appear in the other bags. The average gram/mile NOx emission increase seen at ACR for each bag of the FTP is shown in Table 7.

Table 6: Average Bag Emission Data from ACR Test Program

Test Cycle	A/C	HC	NMHC	CO	NOx
Composite FTP	Off	0.108	0.088	0.965	0.214
	On	0.129	0.110	1.460	0.411
	% Diff	+19%	+25%	+51%	+92%
FTP Bag 1	Off	0.389	0.349	3.256	0.416
	On	0.452	0.417	4.715	0.672
	% Diff	+16%	+19%	+45%	+62%
FTP Bag 2 & 3 Composite	Off	0.036	0.020	0.374	0.164
	On	0.045	0.031	0.631	0.349
	% Diff	+27%	+50%	+69%	+113%
Start Cycle (Bag 1 of REM01)	Off	0.579	0.523	3.038	0.822
	On	0.549	0.505	3.866	1.569
	% Diff	-5%	-4%	+27%	+91%
High Speed (Bag 1 of REP05)	Off	0.065	0.050	2.033	0.224
	On	0.080	0.062	3.523	0.321
	% Diff	+22%	+24%	+73%	+44%
High Load (Bag 2 of REP05	Off	0.283	0.219	17.254	1.029
	On	0.400	0.313	30.504	1.210
	% Diff	+41%	+43%	+77%	+18%

Table 7: Average NOx Increase on FTP--Based on ACR Data

Avg. Increase over Non-A/C	Bag 1	Bag 2	Bag 3
NMHC	0.014	0.003	0.005
CO	0.301	0.056	0.142
NOx	0.053	0.065	0.079

The effects of A/C operation on NOx emission levels were more pronounced on the slower speed cycles. For both the FTP and the Start Cycle the NOx emissions increased by about 90 percent. Only half as much percentage increase was seen on the high speed cycle and an even lower increase was seen on the high load cycle.

CO emissions also increased during the FTP, however much of that increase may be due to the load effect of air conditioning triggering periods of enrichment.

One vehicle, the Caprice, showed essentially no increase in NOx emissions with the A/C running. However, the engine-out NOx emissions increased by 69%, which is within the range of the other vehicles. For all vehicles, engine-out NOx increases ranged from 57% to 117% (average of 80%). The small increase in tailpipe NOx emissions can be attributed to an increase in catalyst efficiency. With the A/C off 6.3% of the exhaust stream NOx was unconverted. With the A/C on only 3.4% of the exhaust stream NOx was unconverted. Table 8 contains specifics of the performance of the Caprice. The data in this table is compiled from the second-by-second emission data.

Table 8: Caprice Composite FTP Emission Results

Testing Mode	Engine-out NOx (grams/mile)	Tailpipe NOx (grams/mile)	Catalyst Efficiency
A/C Off	1.89	0.119	93.7%
A/C On	3.28	0.120	96.4%
% Increase	69%	1%	

Table 9: Modal Distribution of NOx Emissions on Bags 2 & 3 (hot stabilized driving) of the FTP (grams)

Data Element	Idle	Accel	Cruise	Decel	Total
A/C Off (grams)	0.039	0.581	0.697	0.065	1.382
A/C On (grams)	0.286	1.011	1.426	0.222	2.945
Difference (grams)	0.247	0.430	0.729	0.157	1.563
Percent Increase	629%	74%	105%	241%	113%
% in mode	16%	28%	47%	10%	100%

EPA also analyzed the modes of driving where emissions increased. Table 9 summarizes the average modal breakdown of NOx emissions calculated from the second-by-second ACR data for the hot stabilized portion of the FTP (bags 2 and 3). As seen in this table, almost half of the emission increase is due to idles and accelerations. This percentage is likely to be higher because the modes which are identified as "Cruises" contain some accelerations and decelerations that contribute to the emissions increase but that are categorized as cruises. The Agency has analyzed the range of accelerations which occur during a defined "Cruise" mode, finding that emission results peak during the small accelerations included in the cruise, indicating that most cruise-related emissions occur during these acceleration modes. Consequently, the values in the previous table overestimate the effect of true cruises and underestimate the effect of accelerations on NOx emission formation.

Section 3: Controlling A/C-on Emissions

3.1 Causes of A/C-on Emission Increases

The Agency approached the control of A/C-on emissions in the same manner as the other control areas (aggressive driving and intermediate soaks), in that much of the testing, particularly the testing at AC Rochester (ACR), was designed to both assist the Agency in identifying causes of emission changes and to provide data for performing an emissions assessment. EPA believes that the current FTP does not adequately or appropriately represent the additional load imposed on an engine by an operating A/C system, and expected some level of emissions increase due to the load impact when the A/C system is actually turned on. The magnitudes of the increases, at least with respect to NOx, were surprising.

While the Agency focused on NOx impacts because of the large observed increases, the testing at ACR did confirm that HC and CO were also impacted by A/C operation. The bag emissions data from ACR showed average increases of 50% and 72% on a hot stabilized LA4 for tailpipe NMHC and CO, respectively. The tailpipe HC increase could not be traced to an increase in engine out HC levels. Analysis of the engine out data showed essentially no change in THC when the A/C is turned on, so the observed increase was judged to be related to the functioning of the catalyst. On the other hand, engine out CO increased by about 25% when the A/C is turned on. The Agency believes that these increases are related to the increased load on the engine triggering additional periods of commanded enrichment when the A/C is on. A relatively greater increase in CO is expected because of its proportionately greater response to enrichment than NMHC.

The increases in tailpipe NOx with the A/C on at ACR could clearly be linked to large increases observed in engine out NOx, which are probably caused primarily by higher combustion temperatures due to the additional load of the A/C system. In proportion to road load, the load of the A/C system is greatest at idles and lower speeds, causing the bulk of the impacts to appear over this type of driving, a phenomenon noted earlier. In addition, the reduction of NOx in the catalyst is also dependent on air/fuel ratio. The Agency noted some large NOx increases on vehicles that employed a lean-biased air/fuel control strategy or an air/fuel ratio that tended to be poorly controlled in general, and hence, experienced relatively worse NOx conversion efficiencies. Another potential contributor to increases in all three constituents are vehicles that, through the use of the on-board computer, make significant changes to the engine calibrations when the A/C is operating, resulting in detrimental emissions impacts that clearly are not represented on the current FTP.

3.2 Approaches to Compliance Testing for A/C-on Emissions

Two significant elements need to be defined to describe a compliance test for A/C-on emissions. A driving cycle must be chosen, and a method by which to "simulate" A/C operation must be selected. The Agency has considered several options for both of these elements, and this section documents these considerations.

3.2.1 Alternative Methods of Simulating A/C Operation

The Agency believes that the best simulation of the emissions impact of air conditioner operation on typical high ozone days is testing with the air conditioner operating under a full simulation of high ozone climatological conditions, such as the test program performed at General Motors' environmental chamber facility detailed in the previous section. Recognizing the high cost of requiring full environmental simulations as part of the certification testing regime (including the Agency's in-use test programs), the Agency is investigating several alternatives that may prove to be more cost-effective. Each of these alternatives will be evaluated by the Agency on the basis of its ability to: 1) provide real in-use emissions reductions; 2) provide reasonable and proper incentives to the manufacturers, as well as provide appropriate credit for control actions taken by manufacturers; 3) simulate the emissions response and air conditioner behavior parameters observed during typical high ozone conditions over the types of driving that most concern the Agency; and 4) be transportable across all Agency and manufacturer testing programs. As was stated in the previous section, the Agency's interest in the data collected in the environmental chamber is in establishing bench mark emissions and air conditioner compressor parameters against which the alternative proposals can be compared. These alternatives largely focus on methodologies that could be implemented in existing testing laboratories with minimal additional equipment or facility requirements.

Three principle options for simulating air conditioner operation on a given test cycle are being investigated by the Agency. The most theoretical and least developed is a methodology that would dynamically simulate the load of an air conditioning system directly on the vehicle's engine, most likely by applying a predetermined A/C load "trace" via bench equipment (a "mini-dynamometer" that would replace the air conditioner compressor, for example) and existing components of the air conditioner system. A second procedure proposed and under development by manufacturers would make use of the advanced capabilities of the large-roll electric dynamometer to apply the air conditioner load at the dynamometer, in effect achieving a more accurate and more sophisticated version of the current loading methodology. The third air conditioner simulation methodology that the Agency is considering is a test protocol where the air conditioner would be turned on for the duration of an emission test. As in the other options, this test would not necessarily require an advanced environmental chamber and a full simulation of high ozone conditions, but could be carried out in most standard test cells with little modification. In addition to investigating these pure simulations, the Agency also investigated test procedure options that would test with the A/C actually operating. Practical considerations of cost and feasibility caused the Agency to investigate "short-cut" A/C-on approaches that could be conducted in a standard test cell but that would represent the impacts seen under a full environmental simulation such as that at ACR. Detailed discussions of the Agency's investigation of these options appears in following sections.

3.2.1.1 Direct Dynamic Load Simulation

3.2.1.1.1 Description

One approach to duplicating the effect of an operating A/C system on vehicle loading and emissions would be to duplicate the required cooling load where it occurs at the compressor. Conceptually, this approach would require the following two elements: 1) a baseline time record of actual compressor shaft horsepower (Hp) obtained over a driving cycle conducted at a specified set of ambient test conditions and with the AC system operating; and 2) replacing the compressor loading normally applied by the demands of the A/C system with an auxiliary dynamometer set-up that duplicates the compressor loading of the baseline compressor record. The first step would be done once on some basis (perhaps once per engine family, for example), and the second step would constitute the actual emission test procedure to be performed on a regular basis on all emission test vehicles.

3.2.1.1.2 Discussion

A baseline time record of compressor shaft Hp would be obtained during a driving cycle where the A/C load demands are controlled by a specific set of ambient test conditions of air temperature, road surface temperature, relative humidity, solar load, vehicle interior temperature, and ambient air flow speed around the test vehicle. To routinely obtain the desired set of ambient test conditions and conduct the baseline test would require a full environmental test cell with a chassis dynamometer. However, the facility would not require emission test capabilities. Once the manufacturer has determined the baseline compressor Hp record, subsequent emission tests may be conducted in any standard emission test cell by simulating this baseline compressor Hp record with an auxiliary compressor dynamometer. This method might also allow for determination of the compressor Hp as a function of speed and acceleration on the road, which would result in Hp values that could translate to any cycle on the dynamometer. The Agency might specify a minimum set of environmental conditions under which the determination would be made, but use of an expensive environmental test facility would not necessarily be required.

Standard procedures are already known for determining the A/C compressor baseline shaft Hp information that this approach requires. A manufacturer's effort necessary to instrument and conduct this baseline testing would be a function of the number of baseline determinations the final EPA A/C test protocol required.

A brief scrutiny of available commercial dynamometer units did not indicate any shelf units that provide what is needed to perform the type of A/C compressor load simulation required by this approach. Since EPA does not currently have the resources necessary to perform dynamometer development work, this discussion of an alternative method of applying A/C load to a test vehicle is limited to a conceptual discussion at this time.

The additional test effort required for the installation of a compressor dynamometer for A/C testing is a function of how the configuration of the dynamometer might interface with the existing vehicle's A/C system. The following are three conceptual configurations that are discussed in the order of their expected utilization effort. For this discussion, it is assumed that the vehicle's A/C compressor can be isolated from the remainder of the A/C system, and for the first two configurations the inlet and outlet ports of the compressor are assumed to be available to connect to some type of a compressor dynamometer.

The first approach for simulating A/C loads would be the simplest dynamometer configuration and easiest to install for routine testing. Load might be applied to the vehicle's A/C compressor by using the compressor as an air pump working against a controlled pressure restriction. The resultant compressor loading is controlled by varying this restriction with a servo mechanism such that it duplicates the original baseline compressor load record. Lubrication of the compressor normally provided by the A/C system's coolant fluid would be provided by spraying lubricant into the inlet air line to the compressor. Two questions that would either eliminate this approach from consideration or significantly complicate its application are: 1) does air have physical properties that make its application in this manner impractical; and 2) does the dynamometer fluid system of air have to be a closed system rather than the preferred open system? The open system would constantly take in a new source of air and discard the compressed air after the restriction.

The second approach for simulating A/C loads is similar to the first approach except that the dynamometer system for applying load to the vehicle's A/C compressor is accomplished by connecting it to a separate supplemental A/C system that is complete except for a compressor. The supplemental A/C system would need cooling capabilities larger than any expected vehicle's A/C system so that excess cooling capacity was always available. Except for compressor fitting differences, it would be expected that the same supplemental system could be used for all test vehicles. The loading obtained at the vehicle's compressor would be provided using the same method of control used for the first approach. The method of simulation load control would replace the original supplemental A/C capacity controls. The mechanism for providing cooling to the supplemental A/C condenser and discarding the evaporator cooling may present some test cell handling problems. If the previous approach utilizing air for compressor loading had significant development or implementation problems, this second approach might look like a more practical approach.

The third approach for simulating A/C loads would require replacing the vehicle's A/C compressor with a hydraulic pump that would be driven by the engine in a manner identical with how the compressor is driven. The method of load control for the hydraulic pump applies the same principles as discussed previously. This approach is probably the easiest to adapt from proven commercial hardware. However, the installation of a hydraulic pump in all the potential locations that A/C compressors are currently located with the correct drive belt alignment would present a significant test installation problem.

The following list details some of the advantages and disadvantages that might result from a system that loads the A/C compressor in a manner identical with a defined baseline loading requirement as described in the three options above.

Advantages:

1) The loading on the engine would duplicate precisely the baseline compressor loading effects on exhaust emissions, including transient compressor and vehicle idle operation.

2) Variations in compressor loading would be applied to the engine in the same real-time sequence that occurred during the baseline test.

3) Direct compressor loading that is truly representative of the baseline test conditions provides a positive procedure for evaluating and rewarding A/C design improvements that affect compressor loading requirements, and, therefore, emissions.

4) Provides a procedure by which A/C emission testing known to be representative of compressor loading for a specific set of ambient test conditions could be done in a standard emission test cell.

Disadvantages:

1) The A/C emission testing set-up time and the potential of voided tests would be significantly increased. Depending on the final testing sequence selected by the Agency, the logistical problems associated with compressor loading might be prohibitive.

2) The interaction between engine calibration and the A/C compressor load is not maintained. The computer changes parameters based on an expectation of A/C compressor operation (clutching on and off) that does not occur in this approach. Also, the computer would not be able to anticipate the load introduced by the independent source and anticipatory changes to operating parameters would not happen that would also normally occur in actual driving. With current designs of A/C which cycle infrequently at 95°F this concern may not be large, but concerns may be greater with respect to future unknown designs.

3) The compressor loading approach may not be the most desirable in terms of EPA in-use surveillance and confirmatory testing because of the potential difficulty of installation.

4) The required baseline A/C compressor loading record is an additional test requirement that could present instrumentation and facility problems for some manufacturers because of the requirement to simulate some fairly extreme environmental conditions.

5) An A/C compressor dynamometer is additional hardware element that would require maintenance and calibration.

3.2.1.1.3 Summary

Even though there is currently no working system that will apply the required loading directly to the compressor, the development of such a system is highly probable given time and resources for development. Considering the operational disadvantages inherent in a compressor dynamometer approach and the lack of a working compressor dynamometer system, EPA is not likely to advance this alternative method of simulating the affects of A/C operation on emissions as the primary approach in the NPRM.

3.2.3 Simulating A/C Load with a Dynamometer

Given the increased capabilities of the recently installed large-roll electric dynamometers at the Agency's emissions laboratory and some manufacturer laboratories, as well as the likelihood that this kind of dynamometer will be required for much of the future testing by vehicle manufacturers and the Agency, using the dynamometer to simulate air conditioner operation represents a potentially viable option. Based on a preliminary investigation by Nissan, as well as universally held concerns with alternative methods, a consortium of manufacturers has taken the initiative to develop a methodology for this approach. While the dynamometer is capable of applying loads in addition to the basic road load, with any such approach the real issue is how to determine the appropriate load to apply with the dynamometer.

3.2.1.2.1 The Nissan-1 Method

At a meeting called by manufacturers on June 13, 1994, and that Agency representatives attended, Nissan presented a draft proposal (available in the public docket for review) for using the electric dynamometer to represent the load of the air conditioner during an emissions test. This approach came to be known as "Nissan-1." Nissan also presented some preliminary results from one vehicle that they ran through the procedure for illustrative purposes. Generally, the Nissan approach involves four steps:

1) Measure the load exerted on the engine by the air conditioner under a pre-defined set of environmental conditions, presumably those defined and used by previous environmental chamber testing.

2) Mathematically determine the force exerted on the dynamometer for each gear with the air conditioner operating.

3) Fit a least-squares regression to the measured load and speed points.
4) Calculate the overall load curve by adding the regression curve determined above to the base vehicle road load curve.

Although their example procedure was run in a standard test cell at 77°F, Nissan proposed that the load determination procedure be carried out in a sophisticated environmental chamber, using the "Speed Control" feature of the electric dynamometer to calculate the incremental load caused by the air conditioner at the dynamometer roll. The parameters in the environmental chamber would be set at the levels discussed earlier that the Agency believes represent the conditions that contribute to and aggravate high ozone occurrences, including temperature, humidity, solar load, and pavement temperature. They also proposed that this procedure be completed on the eight vehicles that were involved in the previous environmental chamber test program, with Agency followup testing to implement the new overall load curves developed in the environmental chamber at the Agency's laboratory in Ann Arbor, Michigan. General Motors and other manufacturers agreed to support further development of this approach.

Using this approach, the air conditioner load would be calculated at several steady-state speed points up to 60 miles per hour. Specific speed points would be calculated on a vehicle basis by first driving the vehicle with light acceleration through all the forward drive ratios, noting speeds at which the vehicle shifted.[12] The target speed points for performing the load calculation would be the mid speed for each drive ratio, plus each 10 mile per hour speed point from the last (highest speed) mid point speed up to 60 miles per hour. In sequence from low to high speed, with the air conditioner operating (maximum cooling, with recirculation, fan speed setting number two), the vehicle would then be driven to each target load mapping speed point and held there until some cabin temperature stability criteria were met. (It was originally proposed in a General Motors test plan write-up that the vehicle would be held at the target speed plus or minus 0.25 miles per hour, but it became quickly apparent that this tolerance would have to be widened for

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The eight test vehicles that would be used to shake down this approach are all equipped with automatic transmissions. Obviously, a means to deal with standard transmissions and shift points would need to be developed for this approach to be complete.

feasibility reasons.) Once the cabin temperature stability criterion is met, the vehicle would be held at the target speed for one minute while recordings were made of the average dynamometer road force, throttle position, and average M.A.P. After one minute, the dynamometer would be set to the speed control mode and commanded to "Hold Target Speed" and the air conditioner turned off. The throttle position is then adjusted so that the average M.A.P. obtained in the last step is matched, then that M.A.P. is held for one minute while recordings are made of average dynamometer road force, throttle position, and average M.A.P. The vehicle is then shifted into the next highest gear and accelerated to the next load mapping target speed point, where the air conditioner load determination procedure is carried out again.

3.2.1.2.2 The Nissan-2 Method

Returning to the second-by-second data collected in their environmental cell, General Motors calculated the second-by-second air conditioner horsepower and force at the dynamometer during the FTP for three of the eight vehicles that were part of the original test program at their New York environmental chamber. The air conditioner horsepower ranged from about 2 Hp to peaks of about 13 Hp. The calculations on these three vehicles served as a preliminary look at the air conditioner loads experienced over a driving cycle and helped assess actual transient loads, but only served as a proxy for actual measurements of the air conditioner horsepower. Based on these data, General Motors came to believe that the Nissan-1 approach would probably consistently under-predict the actual air conditioner load, and began to seek and define improvements to the methodology. They also believed that the Nissan-1 approach would probably not adequately simulate or account for load impacts under transient conditions, one of the concerns voiced by the Agency. Partly in response to Agency concerns with the "Nissan-1" approach and partly in response to these implementation issues and shortcomings discovered while further developing the approach, the manufacturers revised the approach and presented proposed revisions to Agency representatives on July 26, 1994. The revised approach was christened "Nissan-2."

There are two significant differences from Nissan-1 in the Nissan-2 methodology. The first is that the air conditioner load is determined over an actual driving cycle (presumably to be the Agency's control cycle) rather than unrepresentative steady-state conditions. This approach would also "bake" the vehicle prior to driving the test in order to achieve some representative level of heat build in the interior of the vehicle, whereas the Nissan-1 approach would have been conducted without such a soak. Second, the procedure for actually determining the air conditioner load is radically different. The final result - a load set that can be added to the base road load of the vehicle to get a total road load plus air conditioner curve to the programmed into the dynamometer - is the same, but instead of calculating the air conditioner load at specific speed points, the Nissan-2 approach would measure the air conditioner horsepower directly at the compressor shaft on a 1-second basis throughout the duration of the test. Every time point of the test therefore has an associated speed and air conditioner load, illustrating, among other things, that the air conditioner load is not a constant at a given speed, particularly the lower speeds. The Nissan-2 approach proposes then taking the load and speed data and regressing vehicle speed against air conditioner force at the dynamometer to obtain an estimated air conditioner dynamometer load curve. General Motors proposed using a sixth order regression equation to provide the best possible fit to the data. As in Nissan-1, this curve would then be added to the vehicle's base road load curve to obtain an overall load curve.

As of this writing, General Motors has proposed to test the three vehicles mentioned above with the mathematically developed road load plus air conditioner load curves at their facility in Milford, Michigan, then compare the emissions and compressor/condenser behavior data to the test data from those same vehicles obtained in earlier testing at their environmental chamber facility in New York. If the comparison is favorable, i.e., if the results are similar, then all eight vehicles from the original test program would be returned to the New York facility for the more accurate development of the air conditioner load curves by direct measurement as described above. Following this additional testing, the Agency has committed to continuing the investigation into this methodology with testing on the eight vehicles at the Ann Arbor laboratory. These tests will be performed under standard test cell conditions with the new dynamometer load curves applied, and the results will be compared to the test results from the previously described program at General Motors' New York facility as well as to data collected at the Agency's Ann Arbor laboratory (details of the latter test program are discussed in the following section).

3.2.1.2.3 Discussion of Dynamometer Simulation Methodology

Although a dynamometer simulation methodology has many significant advantages, as of this writing the Agency does not have enough information about its emission accuracy and ease of implementation with which to make a reasoned decision about its merits. Further analysis and testing by the manufacturers should cause the information the Agency requires to be forthcoming by early 1995.

One of the principle advantages of a dynamometer load simulation, of course, is that such a procedure should be relatively easy to run. Other than an electric dynamometer, no special test cell equipment is required and no non-standard test cell ambient conditions need be simulated for emissions testing. There will be some added cost because of the requirement that the air conditioner dynamometer load be developed in an expensive environmental chamber, but such an approach has a clear cost advantage over requiring all emission tests to be conducted in an environmental chamber which are not typically designed and constructed with emissions testing capabilities. If the load determination process includes some vehicle soaking and operation under "real world" high ozone conditions, then vehicle and air conditioner system technologies that reduce the impacts of those conditions on the load experienced by the air conditioner will be justly rewarded by the procedure. A favorite example of this is the installation of window glass with low heat transmission to the vehicle interior. Another example is a vent fan system that senses interior temperature, and when the interior temperature exceeds the outdoor ambient temperature by a certain amount the fan begins to replace the interior air with outside air. All these innovations and others would realize emission benefits by reducing the load on the air conditioning system, which is a significant advantage to this type of procedure.

Throughout the development of this approach, the Agency has voiced several important reservations. Two of the significant concerns relate to the fact that a dynamometer approach is inherently an approach in which the air conditioner is never actually turned on. First, a dynamometer load simulation can not provide an increased load when the vehicle is standing at idle. This is an important consideration because of the fact that testing performed by the Agency in 1994 demonstrated that operation of the air conditioner can cause significant emissions increases, particularly in NOx, while at idle. Later testing by the manufacturers demonstrated less of an impact, but the Agency remains concerned about any test method that completely omits testing for impacts at idle. Given this, if a dynamometer load approach is adopted it is likely that the Agency would seek a separate test of emissions at idle with the air conditioner actually operating. This would necessarily involve additional testing burden, as well as require the Agency to develop an appropriate method and standard by which to test the emissions at idle.

The second major concern is that, by definition, a dynamometer simulation approach focuses solely on the load of the air conditioner, ignoring transient effects and any other effects that may contribute to the emissions impact of air conditioner operation. The Nissan-2 approach does a better job of capturing the transient effects of the air conditioner load and to the extent that these impacts influence the regression curve these impacts are partially accounted for. However, the very nature of using a speed versus load regression to calculate the dynamometer loading curve is a tendency to "smooth" out, or average, the load impacts for a given point in the driving cycle. In some cases, the regression calculated load at a given point on a driving cycle trace will be less than the actual load the vehicle experienced at that point in the trace, while at other times it may be more than the actual load "seen" by the vehicle's engine. In crude terms, this approach takes all the loads measured at a given speed, wherever that speed occurred in the trace, and averages those loads. In emissions testing, then, every time that speed occurs that average load is applied by the dynamometer. A more "pure" approach to dealing with this issue would be to simulate the actual measured loads where they actually occurred in the trace, i.e., applying a time-based load trace to the test procedure.

In response to Agency concerns that applying an "average" load did not represent or account for cycling of the A/C compressor, the manufacturers indicated a willingness to modify the test procedure such that the cycling of the compressor was measured and then duplicated on the dynamometer by selectively shutting off the A/C load at predetermined points in the driving cycle. This is mostly an issue of future technologies or those current ones not represented in the limited fleet of vehicles tested by the Agency and manufacturers, since Agency and manufacturer testing has indicated that the compressor is not likely to cycle in current technologies tested under the ambient conditions specified for the ACR test program. Without this modification, the test procedure would not provide an adequate incentive for appropriate technological responses to the issue of emissions control with the air conditioner on. For example, one suggested response to reduce such emissions is to cycle the compressor off for 1-3 seconds during accelerations. It is unclear whether, without the modification, the Nissan-2 approach would encourage this or other appropriate emission control responses.

Both the Agency and the California Air Resources Board also remain concerned about adequately accounting for calibration responses of the vehicle to the operation of the air conditioner. Today's vehicle technologies can easily anticipate the actions of the air conditioner and account for the upcoming impacts by making changes to the vehicle calibration, changes that are certainly not accounted for in the current FTP and would likewise not be accounted for in a dynamometer load simulation.

An important positive aspect of this type of approach is the fact that it makes use of a sophisticated environmental chamber facility to duplicate exactly the types of conditions that the Agency is most concerned about. As the Agency has stated, the best simulation is the best duplication of those high-ozone conditions, either in the real world or in a test facility that can come very close to duplicating the real world.

3.2.1.2.4 Summary

The Agency believes that a Nissan-2 style of approach may very well be a viable approach, but needs to evaluate data from upcoming test programs in order to make a reasoned and supportable decision regarding the merits of such an approach. Consequently, the Agency can not at this time recommend nor discard this option, but will investigate the data as it becomes available.

3.2.1.3 Testing with A/C On with Less than Full Environmental Simulation

3.2.1.3.1 Introduction

One way to save on the expense of running a full environmental test is to remove elements of ambient control so that the test can be run in a normal cell (perhaps with limited modifications). The major goal of such a procedure would be to establish a test procedure that finds a similar emission effect as that seen in the full environmental cell. It is also important that the test entail a comparable amount of A/C load as seen in the full environmental cell. The EPA reasoned that if the A/C load was similar then EPA could expect the procedure to work well with other types of vehicles and different designs. Setting aside for the moment the question of whether a meaningful shortcut could be designed, the EPA sees several principle advantages to this approach.

Testing with the A/C actually on would allow the full interplay between the engine calibration logic of the computer and the load imposed by the A/C. The on-board computer would be able to anticipate the engagement of the A/C and perform whatever changes it chose to employ (such as increasing idle speed or changing fuel calibration). This strategy is used to some extent in current vehicles and it is anticipated to be used more widely to control A/C emissions impacts in the future. Only this option (of the three options considered to a full environmental test) accomplishes the real-world coupling of A/C operation and calibration control and measures its emission effect.

Testing with the A/C operating also allows the load dynamics of the A/C to be fully represented during the testing. Clutching of the A/C would be properly accounted for during this type of testing. The option to match A/C load on the dynamometer does not fully address the dynamic loading concern.

Concerns about clutch activity does not seem to be especially important to the current design of A/C systems. The A/C generally runs during all driving modes unless the ambient temperature and humidity are low enough to lead to possible overcooling of the operating fluid and icing in the condenser. However, the Agency anticipates that some manufacturers may choose to turn the A/C off during certain short modes (such as the low speed portion of accelerations or idles) to reduce NOx emissions to comply with these rules. Once this strategy is employed, the proper simulation of load dynamics of the A/C becomes important.

The most significant concern with this type of procedure is its lack of ability to properly credit design improvements which are based on reducing the transmission of solar energy into interior heat. The Agency is also concerned about the possibility that the procedure will cause manufacturers to optimize emissions for the "short-cut" procedure, which may not translate into actual in-use emissions reductions. There is also the possibility that the short-cut may overstate emissions on some yet-to-be-conceived A/C technology.

The most important element in defining a suitable short-cut A/C-on testing protocol is setting the ambient conditions. The goal of the control cycle is to match emission results obtained at the test conditions selected to represent ozone exceedance days. As discussed in the development of the ACR test program (See Section 2.2), the ambient conditions of interest are:

- Temperature: 95°F
- Sun Load: 850 watts/meter^2
- Humidity: 40% relative humidity
- Pavement Temperature: 135°F
- Interior Temperature: 1 30°F minimum, equilibrium temperature based on solar load

- Cooling: Based on vehicle speed

The choice of ambient conditions also impacts the cost of testing. Temperature control is the cheapest ambient control element. Sun load requires special heating lamps. Full vehicle cooling based on vehicle speed requires a wind tunnel. Clearly there are important trade-offs between cost and the complexity of the ambient simulation. The unanswered question is how sensitive the vehicle might be to precise control of these ambient parameters. Is it possible to develop a short-cut test that identifies most of the emissions impact at a substantial cost savings? The EPA developed a test program to answer that question.

3.2.1.3.2 EPA Test Program to Develop Alternative A/C-on Procedure

EPA acquired emissions and A/C data during three specific test configurations. A copy of the Agency's test plan is contained in Appendix E. The first configuration was in the A/C-off mode with the cell temperature at a nominal 75°F and a dew point of 47°F, the second configuration was the same except with the A/C on, and the third condition was with the cell temperature at 95°F with a dew point of 44°F and the A/C on. Vehicles were tested on the LA4 driving cycle in a hot stabilized condition. The exceptions to the above conditions are detailed below.

With the exception of tests specifically designated for the Transport, all vehicles were equipped with standard gas caps. On the designated tests involving the Transport, a vented gas cap was installed. Another exception to the above protocol was again with the Transport. Two designated tests were conducted on the Transport with the cell temperature at 95°F and two 1,200 btu electric heaters inside the van, wired to operate continuously. The cabin temperature was at a nominal 130°F for these two tests. During these two tests, all windows were in the closed position. For all other testing of the Transport and all other vehicles, the drivers-side window was down.

The emissions data were obtained using the standard methodology for collecting Bag #1 and Bag #2 FTP emissions data as described in the Code of Federal Regulations (40 CFR 86 Subpart B). All speed tolerances for the standard FTP driving schedule were adhered to for all test configurations.

The A/C pressure and temperature data were acquired using the instrumentation provided by the respective manufacturers. Analog signals were provided by the manufacturers "read-out" boxes for engine rpm, throttle position, A/C clutch signal (on/off), A/C compressor head and suction pressure, and temperatures of the condenser, head-rest, right A/C vent, and engine coolant. EPA also installed a voltage lead from the A/C clutch on some of the vehicles. All of the above signals were fed to an EPA data acquisition system using Lab View as the signal processing protocol. The data scan rate was set for 1 Hz. Post-processing of the data was accomplished using Lotus 1-2-3. A hard copy of these data are found in Appendix E.

A single 36 inch Hartzel fan was used for vehicle cooling in all test configurations. No side cooling was provided at any time. The fan has a variable speed control, however, the fan operated at a fixed setting of 59 percent which resulted in an air flow of approximately 15,000 CFM for all conditions (approximately 25 mph).

Prior to acquiring any emission or analog data, each vehicle was preconditioned by operating 22.8 minutes on the LA-4 driving cycle. The vehicle was then shut off for 10 minutes. Following the 10 minute soak the vehicle was operated at 50 mph for 3 minutes, and then emissions data and analog data were acquired.

3.2.1.3.2.1 The 75°F Test Data

The first condition EPA explored was running with the A/C on in the standard test cell. The temperature was 75°F, the humidity was 50 grains/pound of dry air, there was no sun load, cooling was provided by means of a 15,000 CFM fan, and the drivers' side window was open (other windows were closed). The A/C-on test was run with the A/C mode switch in the maximum/recirculation condition, the temperature slide bar was fully to the cold side, and the fan was set in the third position of four. The data from this program is contained in Appendix E.

A comparison between the NOx emissions on the FTP Bags 2+3 of the ACR data and the 75°F EPA test program is summarized in Table 10. Similar comparisons for other emission constituents are contained in the previously referenced Appendix. The 75°F data only represented about 30 percent of the NOx emissions impact observed on the ACR test, and therefore failed to capture the full amount of NOx emissions increase seen at ACR.

Table 10: NOx Emissions (g/mi) in the Weighted FTP Bag 2 + Bag 3 Comparing ACR and EPA 75°F Data

	ACR Data	EPA Data

Test Vehicle	A/C Off	A/C On	On-Off	A/C Off	75°F A/C	On-Off
Astro Van*	0.451	0.836	0.385	0.18	0.298	0.118
Transport	0.088	0.404	0.316	0.286	0.42	0.134
Grand Prix	0.144	0.431	0.287	0.25	0.407	0.157
Civic	0.045	0.171	0.126	0.046	0.154	0.108
Intrepid	0.181	0.256	0.075	0.176	0.092	-0.084
Saturn	0.153	0.261	0.109	0.205	0.242	0.037
Caprice	0.084	0.084	0.000	0.038	0.038	0.000
Average	0.164	0.349	0.185	0.169	0.236	0.067

* Different vehicle tested at ACR and EPA

3.2.1.3.2.2 The 95°F Test Data

The next condition EPA explored was running with the A/C on in the standard test cell but with the temperature elevated to 95°F. The test conditions were: temperature was 95°F, the humidity was 50 grains/pound of dry air (equivalent to about 20 percent relative humidity), there was no sun load, cooling was provided by means of a 15,000 CFM fan, and the drivers' side window was open (other windows were closed). The A/C-on test was run with the A/C mode switch in the maximum/recirculation condition, the temperature slide bar was fully to the cold side, and the fan was set in the third position of four. The data from that program is contained in Appendix F.

A comparison between the NOx emissions on the FTP Bags 2+3 of the ACR data and the 95°F EPA test program is summarized in Table 11. Similar comparisons for other emission constituents are contained in Appendix E.

Table 11: NOx Emissions (g/mi) in the Weighted FTP Bag 2 + Bag 3 Comparing ACR and EPA 95°F Data

	ACR Data	EPA Data

Test Vehicle	A/C Off	A/C On	On-Off	A/C Off	95°F A/C	On-Off
Astro Van*	0.451	0.836	0.385	0.18	0.554	0.374
Transport	0.088	0.404	0.316	0.286	0.632	0.346
Grand Prix	0.144	0.431	0.287	0.25	0.594	0.344
Civic	0.045	0.171	0.126	0.046	0.194	0.148
Intrepid	0.181	0.256	0.075	0.176	0.248	0.072
Saturn	0.153	0.261	0.109	0.205	0.339	0.134
Caprice	0.084	0.084	0.000	0.038	0.027	-0.011
Average	0.164	0.349	0.185	0.169	0.370	0.201

* Different vehicle tested at ACR and EPA

The data shows a very close match of the NOx emissions increase seen at ACR with the NOx emissions identified by a 95°F test without sun load. Individually, all the vehicles had similar emission differences as those seen at ACR. The 95°F differences split evenly between higher and lower than ACR data. Although the number of points is small, there is over 85 percent statistical probability that the two tests yield identical differential NOx emission results.

The compressor head pressure also showed good correlation between ACR and the 95°F EPA data. The raw average 95°F head pressure was 10 percent higher than the ACR data based on the raw data, but when the pressures were adjusted to account for the change in test equipment from ACR to EPA the difference was only three percent. The suction pressure was 21.5 percent lower on the 95°F EPA test than at ACR. The lower suction pressure on the 95°F EPA test indicates that it requires somewhat less A/C work than would occur in use (based on the ACR tests). The good correlation between head pressures indicates that the dynamic load range is similar between 95°F testing and actual in-use (as represented by the ACR tests).

The HC emissions showed good correlation between the 95°F test results and ACR; the differences were nearly zero. The CO emission differences were larger; 0.17 g/mi (ACR) versus 0.38 g/mi (95°F EPA test). Although the percent of change is large the actual level of emissions difference is small and within the range of test-to-test variability on the standard FTP test. The difference is likely due to load-based enrichment which would theoretically not exist on vehicles calibrated to pass the cycle and standards that the Agency expects to propose to address aggressive driving. Consequently, the real differences that would exist on properly calibrated vehicles is smaller yet.

3.2.1.3.2.3 Possible Improvements to the 95°F Test

Although the 95°F test program was very successful at replicating in-use emission differences on current technology A/C systems, the Agency investigated several possible improvements to the environmental simulation. Using one test vehicle (the Transport), EPA ran LA-4 tests at 95°F and the A/C-on with the external Hartzel fan turned off at idles, with the windows up, and with the windows up with a heat source in the vehicle to simulate the impact of sun load. The emission results from these procedures were compared to the basic 95°F test. The results of that testing is summarized in Table 12.

Table 12: Additional 95°F Test Scenarios and ACR Results for Comparison

Test Condition	NOx	HC	CO	Avg. Head Pressure	Avg. Suction Pressure	Delta Pressure
EPA Basic 95°F	0.632	0.02	0.034	195	38.6	156.4
95° Window Closed	0.726	0.02	0.01	183	19.4	163.6
95° Window Closed,Heated	1.02	0.07	0.019	202	31.8	170.2
95° Window Open No Fan @ idle	0.885	0.021	0.014	196	33.3	162.7
ACR	0.404	0.027	0.171			

With the current design of A/C systems (which do not cycle the A/C compressor much, if at all, during 95°F testing) there is little emission impact between open and closed driver's side window. However, the much lower suction pressure (19.4 for the windows up versus 38.6 with the window down) with the windows up indicate a potential short-fall for A/C designs which cycle the compressor more frequently.

The Agency was concerned that the single 15,000 CFM fan may be overcooling the vehicles in some situations. The fan represented about 25 mph wind, which is close to the average speed of the LA-4, but would be too much air at idles, because in actual use at idle the only airflow seen by the engine and A/C system is that generated by the vehicle's own internal fan system. However, the data generated from the EPA testing program showed a slight increase in emissions and little effect on the compressor pressures. Consequently, EPA determined that the overcooling at idles was not significant and may represent an emissions balance with the undercooling at higher speeds.

Although accurate solar heating was not possible in our test cell, EPA approximated the effect of the solar load by adding two 1200 BTU heaters to the vehicle interior. The heaters were set at levels which caused the interior temperature to hit about 120°F. The data showed a NOx emission increase and surprisingly little effect on the compressor pressures.

In conclusion, addition of solar load or reducing cooling both caused NOx emission increases which were beyond the results seen at ACR. Also, with current technology vehicles the window position has little affect on emissions, however, the driver's window down is necessary to obtain compressor pressures which are similar to the ACR data. This reduction in compressor suction pressure could lead to lower NOx emissions than measured in-use for vehicles which cycle the A/C compressor.

3.2.2 Choosing a Control Cycle

Theoretically, a control cycle should include all modes of driving which occur in use. There is no indication that people use their air conditioners any differently in one driving mode than another. Air conditioning usage is largely based on the ambient conditions, not on driving modes. Still, if the EPA could obtain a full range of emission improvement in all driving modes without actually requiring testing in each mode it would be desirable from a cost standpoint and would have no loss of stringency in use.

The data collected from the ACR test program showed that emissions were more significantly impacted by A/C operation on the FTP than on other cycles. The average impact on NOx emissions is approximately 92% for the FTP, 91% on the ST01, 44% on the high speed portion of the test (REP05 Bag #1), and 18% on the high load portion of the test (REP05 Bag #2). The EPA discovered that most NOx emissions occurred during accelerations and idles. In analyzing the total grams of NOx emissions during the FTP, the EPA determined that on the average at least 28% occur during accelerations , 16% at idles, and less than 47% on cruises. Consequently, the type of cycle that best evaluates the effect of A/C operation is a slow to moderate speed cycle which includes accelerations.

3.2.2.1 Inclusion of Cold Start Emission Test

To save costs, the EPA explored the possibility of eliminating part of the full FTP as the control cycle. From a cost standpoint, eliminating the Bag 1 would generate the most cost savings due to the 12-36 hour soak required before testing.

Initially the Bag 1 CO increase noted in Section 2.3.5 caused some concern. However, the Agency reasoned that the CO increase must come from one of two sources. Either the CO increase was due to the warmed-up load effect of the A/C or it was due to further cold start emissions associated with A/C operation. The driving schedule of Bag 1 is identical to Bag 3. If the effects were based on the increased load, the same calibration changes which would be implemented for US06 control would solve this problem. Consequently, this portion of the emission increase would be addressed by enrichment control at no additional cost. On the other hand, if the CO emission increases were due to cold start characteristics, control of those emissions before catalyst light-off would not be fully possible. In that case, including the Bag 1 as part of the A/C control strategy would require a larger emission standard which would effectively offset the CO emissions increase observed at ACR.

In balance, the Agency concluded that there is no significant advantage to requiring the Bag 1 cycle, since no further control of HC or NOx emissions is predicted and the effect on CO emissions would be largely offset by higher standards. Clearly, there is a significant cost advantage to removing the Bag 1 cycle from A/C control.

3.2.2.2 Option of Replacing the Hot 505 Cycle with the ST01 Cycle

When the Agency began to consider how to reduce the cost of the individual components of the revised FTP, EPA began to look at ways to share one cycle in two control areas. The Agency also looked at preconditioning cycles which could be parts of other control cycles. One area of potential sharing of control cycles was with intermediate soaks. The soak control program likely to be proposed is the ST01 following a 60 minute soak. The 60 minute soak used for intermediate soak control should not affect air conditioning operation in an unrepresentative manner. The data presented to document intermediate soaks in use would apply equally whether the A/C is running or not. The start cycle is the same mileage as the 505 cycle, which is part of the LA-4 control cycle envisioned for A/C. Table 13 compares the Bag 2 of the FTP with the Start cycle.

Table 13: Average NOx Emissions from the ACR Test Program

A/C Status	Bag 2 of FTP	Start Cycle*
Off	0.113	0.822*
On	0.239	1.569*
Percent difference	111.2%	90.8%

* Includes an engine start after a 60 minute soak

The ACR data shows that percentage changes in emissions between the Start Cycle and Bag 2 of the FTP is very similar. The absolute difference in emissions from the above data is very misleading. The Start Cycle in the ACR test program included an engine start after a 60 minute soak. Consequently, the start cycle has higher emission values than the Bag 2 due to the effect of a cold catalyst. In summary, the Start Cycle should give equal or better control but eliminates a 505 test cycle from the total testing requirements of the revised FTP.

The Agency believes it is reasonable to assume that A/C use occurs over the full range of in-use driving, and the data collected at ACR demonstrated a varying emissions impact over all types of driving. As in the case of the control options discussed in the Aggressive Driving Technical Report, the Agency considered an emissions performance standard applied to fully representative driving cycles. However, the significant disadvantage stated in that section (impacts on testing time and costs) is even more relevant with respect to A/C control.

Assuming air conditioning is used over all types of in-use driving, such an approach would have to use ST01, Remnant, and REP05 to represent all in-use driving, and drive time would approach 50 minutes.

As described in Section 2, the most significant impacts from A/C operation were seen at lower speeds, accelerations, and idles. Increases of more than 90% in tailpipe NOx were seen at ACR on both the LA4 and ST01 cycles, while the average increase on the higher speeds and accelerations of the REP05 cycle was approximately 38%. Given this, the Agency believes that a cycle with slow to moderate speeds and a reasonable number of accelerations and idles could address the emissions increases associated with A/C operation. Since there are advantages to a control cycle with some historical familiarity and reasonable length, as well as one that meets the above criteria, the Agency first considered the full FTP in its current form. However, because the A/C impact is an issue of increased engine-out emissions, the only way to address emissions increases on the cold start 505 (or "Bag 1", conducted following a 12-36 hour soak) is to bring the catalyst to a hot functional condition faster than current technology vehicles are able to do so. This "quick lightoff" technology is expected to become prevalent with tighter standards that take effect after the turn of the century ("Tier II"), but is not required in order to meet the current emission standards. Given that the Agency's goal with revisions to the FTP is to achieve the same level of control in the new control areas that is achieved on the FTP under the currently applicable standards, the Agency believes that the technology-forcing aspect of requiring control of A/C-caused emissions on a cold start test is inappropriate at this time because of the lead-time requirements to implement the new catalyst technology. Consequently, a cold start test is not included in today's proposal, but the Agency does believe that it may be appropriate to return to this issue with respect to future technologies and future test procedures and emission standards. The Agency specifically solicits comment on this issue.

3.2.2.3 The US06 Cycle

The Agency also investigated the possibility of requiring A/C control testing on the US06 cycle, developed to address emissions due to aggressive driving. As noted above and in section 2, some vehicles exhibited significantly increased NOx emissions over driving with high speeds and accelerations with the A/C on. The Agency considered the possibility that some additional level of control might be gained by testing over that type of driving. However, the EPA determined that the average increase was being driven in large part by one vehicle in the ACR test program, and further analysis of the second-by-second data for that vehicle revealed behavior (particularly poor transient control of the air/fuel ratio, for example) that the Agency believes will have to be improved to achieve the levels of emission control necessary to conform to the requirements of the aggressive US06 cycle alone. Because of this, the Agency believes that a test of A/C-on emissions using the US06 is not necessary, nor would it be likely to achieve emission benefits beyond those achieved by the US06 cycle and standards. In addition, an analysis presented to the Agency by the auto manufacturers indicated that the total US06 regime of loads on the engine when the A/C is on is effectively equivalent to the US06 load regime with the A/C off. Preliminary information from the auto manufacturers also indicated some potentially significant problems providing adequate cooling to vehicles tested with the A/C on over the US06 cycle, and resolution of these issues could have significant test cell impacts.

3.2.2.4 Conclusions

The Agency believes that an appropriate control cycle for A/C-related emissions is the LA4 (505 + 866). However, although the potential impacts of micro-transient driving on A/C-related emissions is not clear, the Agency remains somewhat concerned with the unrepresentative "smoothness" of the LA4 cycle and requests comments on possible alternatives. Specifically, the Agency believes that it may be appropriate to substitute the cycle developed to represent start driving (SC01) for the 505 component of the LA4, as they are both of similar distance and time, and the SC01 clearly better represents in-use driving behavior than the 505. There may be some additional benefit beyond A/C control to including more representative micro-transient driving in the A/C test procedure. In addition, this option is discussed as part of the Agency's central proposal in the Notice of Proposed Rulemaking to combine several test elements and composite the emission results for comparison against one set of standards.

3.3 Potential Strategies for Controlling A/C-on Emissions

The Agency is principally concerned with controlling the NOx increases associated with the use of air conditioning. As noted in section 3.1, the emission increases in HC and CO are largely attributable to enrichment events, the control of which is discussed throughout the US06/Aggressive Driving Technical Report. The Agency believes that the control strategies for HC and CO discussed in that report will eliminate HC and CO emissions increases due to A/C operation as well as during aggressive driving. With respect to NOx control, tailpipe NOx can be improved either by increasing NOx conversion efficiency in the catalyst or decreasing engine out NOx. Although the US06/Aggressive Driving Technical Report addresses controlling emissions from aggressive driving behavior, the strategies detailed in that report for control of NOx are equally applicable to mitigation of NOx increases associated with A/C operation, because emissions from aggressive driving and A/C operation are both caused by increased load on the engine. This is particularly so for optimization of the air/fuel ratio for NOx control at the catalyst. Other options also addressed in the US06 Technical Report include addition or enhancement of EGR systems and adjustments to spark timing to reduce combustion temperatures, elimination of the lean-on-cruise strategy, and catalyst improvements to improve NOx conversion efficiency, all of which will lead to reductions in NOx emissions associated with A/C operation.

Engine out NOx levels can also be mitigated by reducing the load imposed by the A/C on the engine or by strategically controlling the cycling of the A/C compressor. Controlling the cycling of the compressor could be accomplished through use of the onboard computer, which already typically senses throttle position, engine speed, and engine load (MAP). These inputs could be used to turn the compressor off for short durations during accelerations, thus eliminating the additional load during critical seconds when the compressor load has its greatest impact on generation of engine out NOx. Compressor cycling could be carefully managed by the computer to eliminate or reduce the load on the engine during accelerations and redistribute it to periods where NOx formation is less affected, such as cruises or decelerations.

Reducing the load on the engine would also cause a reduction in engine out NOx. This load reduction could come from improvements to the A/C system and the vehicle, such as the use of specialized glass that transmits less heat from the sun to the interior of the vehicle. The EPA also believes that innovations in A/C systems likely to lead to efficiency improvements are on the technological horizon that will enable further reductions in emissions associated with A/C operation. For example, the Agency is aware of a recently-developed A/C system that is electrically driven, uses a new low pressure refrigerant, weighs significantly less and is more compact than current systems, and has fewer moving parts than current systems. This system, due to be installed in a fleet of electric buses in 1995, offers potential future innovations such as the ability to run the system with solar power while the vehicle is soaking.

3.4 Level of Emission Control

As in the Agency's approach to determining appropriate levels of emission control for aggressive and soak/start driving, the Agency believes that many of the strategies used to control emissions during driving represented by the current FTP can be applied to control emissions from A/C operation. Additional strategies also exist that are specific to the A/C system and therefore have not yet been considered for implementation on the current FTP. The level of emission control is based both on the observed response of specific pollutants to A/C operation and on the potential strategies that might be employed for control.

3.4.1 Control of HC and CO

Section 3.1 demonstrated that the HC and CO increase associated with A/C operation is largely attributable to commanded enrichment, which will be controlled due to required compliance with the US06 cycle and standards. Thus, the levels achievable on the LA4 with the A/C on should be comparable to levels achieved with the A/C off.

3.4.2 Control of NOx

The level of control applicable to NOx is more difficult to determine. The Agency believes that the large tailpipe NOx increases due to A/C operation can be mitigated to some extent, but because these increases were typically tied to large engine out increases there is probably some increase in tailpipe NOx that is unavoidable with the A/C operating. The difficult issue to address is how much of that observed increase can be eliminated with the potential and feasible control strategies, and therefore, what the level of increase actually is.

As detailed earlier, there are two general strategies that can be taken to reduce the impact of A/C operation on tailpipe NOx. The first is to seek some improvement in the NOx conversion efficiency of the catalyst, particularly via appropriate attention to the air/fuel ratio. An Agency analysis of NOx conversion efficiencies with the A/C operating demonstrated an average reduction across the seven vehicles tested at ACR of 0.10 grams/mile if the three vehicles that had below-average conversion efficiencies had been calibrated to perform at the average level.

The second strategy to reduce tailpipe NOx is to reduce NOx at the engine source, which can be done by lowering combustion temperatures or reducing the load imposed by the A/C system. Combustion temperatures can be reduced by enhancing and increasing EGR use and/or by modifying spark timing, both of which will result in decreased engine out levels of NOx. The Agency has not estimated the reductions that might be achieved by these methods independently, but the auto manufacturers have submitted a preliminary analysis to the Agency that suggests that when combined with improvements to NOx conversion efficiency these strategies might achieve reductions on the order of 0.20 grams/mile of NMHC + NOx. Based on the data collected at ACR, NOx accounts for 80 to 90 percent of the NMHC + NOx equation on average. Given this, a potential NOx reduction of up to 0.18 grams/mile can be extrapolated from the manufacturers analysis, although this figure should be regarded as preliminary. The Agency has also evaluated the potential impacts of mitigating engine out NOx by shutting off the A/C compressor for several seconds on accelerations on the LA4 cycle. Lacking data from compressors that actually behave in this way, the Agency modeled this on the LA4 by substituting A/C-off emissions data for sequences of seconds in A/C-on tests. The result is a modeled decrease of approximately 0.024 grams/mile, or about twelve percent of the average A/C-on increase. While it is the Agency's expectation that actual implementation of this strategy could use inputs to the vehicle's computer to better target compressor-off periods and durations and possibly achieve a larger reduction, the potential benefit might still be small enough to make this a strategy of last-resort because of the manufacturer's concerns outlined in the following section on feasibility.

Overall, the Agency believes that implementation of these strategies can reduce A/C-on emissions increases by 75%, which translates to an "uncontrolled" increase of 0.05 grams/mile with the A/C operating. The extent to which additional innovative control strategies (e.g., more efficient A/C systems, specialized glass, or interior cooling methods for vehicle soaks) can reduce engine out NOx is not easily estimated, but the Agency believes that the level of control defined above will encourage, but not require, the use of such technologies.

Section 4: Technological Feasibility

The Agency believes that the technologies required to produce vehicles conforming to the levels of control discussed earlier in this section are already generally available and in place to varying extent in the current fleet. The feasibility of recalibration strategies (e.g., optimization and tight control of the air/fuel ratio) is addressed in the US06/Aggressive Driving Technical Report. The Agency also believes that the onboard computers in current technology vehicles already typically sense the inputs necessary to implement the strategy of turning the compressor off at critical points. However, potential impacts of this option on vehicle driveability, driver comfort, performance, and emissions and component durability must also be addressed by the Agency.

The Agency believes that performance will be unaffected or possibly improved by selectively shutting the compressor off during portions of some accelerations. Indeed, many current technology vehicles already employ this strategy but restrict it to wide open throttle accelerations, specifically to improve vehicle performance. Because the thermal inertia of the A/C system will cause cold air to continue to be discharged for several seconds following compressor shutoff, driver and passenger comfort should also be unaffected. The possibility that this type of cycling strategy will adversely affect the durability of the compressor does exist, but the Agency does not know how significant a problem this might be. Current technology compressors are designed to cycle on and off many times, perhaps hundreds or thousands of times in a typical day's driving. In fact, this strategy does not necessarily imply that the compressor must cycle more often; to make up for turning it off on an acceleration the system may compensate by not turning it off somewhere else. It should be noted that vehicle manufacturers have stated that this strategy is the least desirable among all the choices and is not likely to be implemented because of potential impacts on customer comfort and satisfaction and the belief that the resulting emissions benefit is likely to be very small. However, the Agency believes that this strategy could be a valid and useful element for addressing A/C-on emissions.

Theoretically, NOx emissions increase with higher cylinder temperatures (generally caused by higher engine loads) and longer residence time in the cylinder (lower engine speeds). NOx formation is also heavily dependent upon air/fuel ratio; leaner air/fuel ratios, up to about 16:1 or 17:1 promote the formation of NOx. Control of NOx emissions at the tailpipe comes from either reducing engine-out NOx or by improving NOx conversion efficiency in the catalyst. Typically-used principles to control engine-out NOx emissions are: controlling air/fuel ratio to slightly rich, reducing cylinder temperatures by adding exhaust gas recirculation (EGR), retarding the spark, and increasing the N/V ratio of the vehicle. The load profile of the engine also impacts NOx formation; higher loads (especially at lower speeds) lead to more NOx formation. Beyond controlling the engine-out NOx, tailpipe NOx levels may be reduced by increasing catalyst efficiencies.

It is clear that including A/C load will fundamentally increase NOx emissions. The higher A/C load will lead to higher in-cylinder temperatures and ultimately to more engine-out NOx. In the ACR test program the average engine-out NOx emission increased by 79% with A/C on.

The engine-out NOx increase may be mitigated through control of the A/C unit. The A/C compressor is already controlled by an electric clutch on all production vehicles. Operation of the clutch is performed by the onboard computer which currently senses throttle position, engine speed, and engine load (MAP). All the hardware is in place to sense when idles occur and when accelerations start and to turn the A/C off for short duration's during accelerations and possibly for some time at idles. Removing the load effect of the air conditioner at low engine speeds will virtually eliminate the NOx increases in these modes. From the ACR data, EPA calculated that idles and accelerations accounted for at least 44% of the NOx increases.

Turning the A/C off for short periods (1-3 seconds) should not be noticeable to the occupants of the car. The thermal inertia of the A/C unit will have to allow the cold air to continue to be discharged for these short duration's even with the A/C off. Driveability will be unaffected, or could even be improved by turning the A/C off for short duration's.

Beyond the potential for limiting the engine-out NOx increases due to A/C operation, there are methods to improve NOx catalyst conversion efficiencies. Catalysts could obviously be reformulated to change precious metal formulations to improve NOx control. Catalysts may also be increased in size or loading rates to enhance NOx conversion efficiencies. However, there is one method which has significantly less cost and appears to give sufficient room for improvement.

Three-way catalyst NOx conversion efficiencies are very sensitive to air/fuel ratio. Based on the ACR test data, NOx efficiencies of 93-98 percent are possible with very tight air/fuel ratio control and slightly rich air/fuel ratios. However, if the exhaust stream goes lean NOx efficiency drops instantaneously. Careful control of air/fuel ratio to slightly rich levels will significantly improve catalyst conversion of NOx. The Caprice test vehicle showed essentially no NOx increase due to A/C operation over the FTP test in the ACR test program. As discussed in Section 2.2, EPA concluded that was due to an improvement in NOx catalyst conversion efficiency. Table 14 summarizes the NOx through-put percent (1-catalyst efficiency) for the FTP Bag 2+3 of the ACR test program.

Table 14: NOx Catalyst Through-put--Bags 2+3 ACR Test Program

Test Vehicle	A/C Off	A/C On	Percent Diff
Astro Van	20.79%	20.96%	-0.80%
Caprice	4.91%	2.61%	46.84%
Civic	1.60%	3.00%	-87.96%
Grand Prix	11.35%	10.32%	9.03%
Intrepid	8.21%	6.43%	21.76%
Saturn	9.93%	8.94%	9.95%
Transport	2.68%	9.03%	-237.30%
Average	8.49%	8.76%	-34.07%

The average catalyst through-put is 8.76% with the A/C on. That is, 8.76% of the engine-out NOx is unconverted by the catalyst. Two of the vehicles have NOx though-puts of 3% or less, which is almost three times better than the average. This indicates a substantial improvement in NOx conversion efficiency is possible Four of the vehicles lowered NOx through-put with the A/C on. In summary, the Agency has concluded that it is possible to meet the A/C emission requirement by controlling the operation of the A/C and by recalibration of the fuel management to control the air/fuel ratio tightly in the slightly rich regime.

Section 5: A/C Test Procedures

5.1 Discussion

The following discussion identifies significant elements of a compliance test procedure designed to address emissions due to A/C operation. Based on the test program discussed above, EPA has concluded that testing with the A/C on at 95°F but without sun load (as discussed in Section 3.2) represents an acceptable short-cut test to measure the off-cycle A/C emissions. EPA has also judged that the advantages of this approach discussed in Section 3.2 and its lower cost than testing in a full environmental cell make it the most appealing option to the Agency. EPA is especially concerned about the potential for engine calibration interactions which are missed with the other two proposals which account only for the load of the A/C system. EPA is also concerned that tables of speed versus load values used to load the dynamometer or directly load the engine would be based on regressions of data which would tend to smooth the data. One particular concern about the dynamometer loading option is how to accurately reflect the load of A/C at idle where the dynamometer cannot supply a load.

However, EPA is not removing the option for a full environmental simulation or another significantly improved simulation which uses the same test cycles. Manufacturers that may desire a better simulation of the A/C emissions effect may run full environmental cell tests (on the EPA control cycle) which add appropriate sun load, road pavement temperature, humidity levels, and cooling. EPA will consider petitions for other 95°F test procedures (using the EPA control cycle) which add only appropriate sun load or humidity. However, EPA will not approve requests for better cooling or closing the driver's window alone (which would lower emissions) without also accounting for the full ambient conditions which increase the load of the A/C unit (which would raise emissions) The driver's side window being open plus the single cooling fan represent the balance of the emissions impact of appropriate cooling with sun load and higher humidity.

In the EPA proposal, this procedure is considered a short-cut procedure. Manufacturers would have the option to run a full ambient simulation in an environmental test cell.

The Agency does not expect that manufacturers will choose the full environmental test option very frequently because of the cost of the test. Also, since this is a pass/fail test, there would be no need to run the better test unless the manufacturer determined that there was a significant risk of failing the standard on the short-cut test.

The Agency believes that it is appropriate to include a test for A/C-related emissions as an element of an expanded Federal Test Procedure. The purpose of this new A/C test procedure is to represent an in-use driving condition that does not occur throughout the year but that has a significant emissions impact when it does occur. As was demonstrated by the EPA survey in Phoenix, A/C use (and emissions impact) is high when conditions are most favorable for the generation of high ozone levels, and the Agency believes that the contribution of A/C-related emissions to high-ozone conditions is substantial.

Based on the conclusions of the previous sections, the principle structure of a test procedure for A/C operation is the LA4 driving cycle run with the A/C operating in a test cell with an ambient temperature of 95°F. However, the Agency expects to provide for the possibility that auto manufacturers may in some cases want a better simulation in a full environmental test facility, an option that will likely not be excluded by the Agency if appropriate simulations are made of temperature, humidity, sun load, road surface temperature, and vehicle cooling. The Agency expects that A/C emission control at temperatures lower than 95°F should be equivalent or superior to control at 95°F, and as a consequence the Agency expects to propose that official confirmatory tests may be conducted at any temperature between 68°F and 95°F. Current regulatory language specifies that an A/C simulation be applied to test vehicles where "it is expected that more than 33 percent of a car line within an engine-system combination will be equipped with air conditioning" (40 CFR 86.129-94), criteria for applicability that the Agency expects to carry across to the new A/C test requirements. All test vehicles meeting this criteria must therefore have a properly functioning A/C system installed.

With the exception of the test environment, the specific test procedures for both the "short-cut" procedure and the full environmental simulation are essentially identical. A large-roll electric dynamometer or equivalent is required. The test should be conducted with the vehicle in a hot stabilized condition, therefore preconditioning over some type of driving will be required. Minimally, the vehicle should be driven over a 505 cycle if it has soaked for less than two hours, but an 866, SC01, or US06 are also acceptable. If the vehicle has soaked for more than two hours, an LA4 or US06 are acceptable preconditioning cycles. Following the preconditioning cycle the vehicle will immediately be driven over the LA4 control cycle and emission measurements will be made. If the vehicle is equipped with a manually operated A/C system, the settings will be as follows: the A/C mode switch will be set to the highest (coldest) position; the temperature control will be set to the lowest (coldest) position; the air flow will be set to discharge from the dash facing the front occupants; air source will be set to recirculation of interior air; and the fan set at position 3 of 4 speeds, position 2 of 3 speeds, or position 2 of 2 speeds. If the vehicle is equipped with an automatic climate control system, the A/C system will be set to control to a temperature of 72°F and the other parameters, if independently selectable, will be set to the specifications for manual systems. However, it has been brought to EPA's attention that there are some fan controls that have up to ten independently selectable positions, and that perhaps a better approach that would achieve more consistent settings across vehicles would be to base the fan setting on amperage.

If the full environmental simulation option is selected, the test chamber should minimally simulate an ambient temperature of 95°F, a relative humidity of 40%, a sun load of 850 Watts/meter2, and wind speed equivalent to vehicle speed. All vehicle windows will be closed. If the alternative procedure is used, the ambient temperature will be set to 95°F, the driver's window will be fully open, and cooling will be provided by a single large fan placed in front of the vehicle.

5.2 Summary of A/C Test Procedure

The next several paragraphs summarize the test conditions and cycles that the Agency believes appropriate for testing for A/C-related emissions.

The test conditions for the A/C test are:

- 95°F ambient (tolerance of plus or minus 5°F)
- The drivers' side window fully open
- Engine cooling from a single fan of up to 15,000 CFM placed in front of the vehicle

- For manual A/C systems:
  - A/C mode switch in the highest position
  - Air source set to recirculation air
  - Temperature slide set to coldest setting
  - Air discharge location will be set to dash board air
  - Fan speed selected at 3 of 4 speeds, or 2 of 3 speeds, or highest speed for 2 speed fans

- For climate controled A/C systems:
  - The temperature selected will set to 72°F
  - The fan will be set to automatic setting or the setting listed above if the fan system is manual
  - Air source will recirculation
  - If selectable, air discharge location will be the dash board