FINAL REPORT

CRC Project E-37

Effect of Air Conditioning on Regulated Emissions for In-Use Vehicles

Phase I

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Section I

PROJECT INTRODUCTION

Establishing reliable emissions inventories is central to identifying and evaluating new pollution control strategies as well as air quality modeling. The challenges associated with characterizing the emissions from mobile sources, in particular, have been daunting. Building models that can predict future emissions levels given the dynamic nature of transportation technology evolution, fleet composition changes, and user behavior is difficult and heavily dependent on timely data.

The research project presented here was undertaken to better understand one specific aspect of this modeling challenge: how the use of air-conditioning (A/C) in light-duty vehicles affects vehicle emissions. This project involved conducting a series of emissions tests involving several different driving cycles, environmental conditions, and fuels. The result of this work is a database that relates how vehicle emissions and fuel economy are impacted by A/C use.

Funding for this project was provided by the Coordinating Research Council (CRC), the California Air Resources Board (ARB), and the Texas Natural Resources Conservation Commission (TNRCC).

Section II

PROJECT BACKGROUND

Motivation for this Project

Interest in this project was stimulated by the concern that the current vehicle emission models being used by ARB and the U.S. Environmental Protection Agency (EPA) do not adequately account for the use of vehicle A/C. Vehicle A/C systems are no longer considered a luxury feature, but have effectively become "standard equipment" across virtually all makes and models. Recent vehicle sales data show that approximately 96% of the cars and 94% of the light-duty trucks purchased in 1997 were sold *with* A/C systems. Further, A/C use is not reserved for summertime. A/C systems are used to establish a comfortable environment inside the vehicle. While ambient temperature is an important factor in A/C use, if the sun is bright, the interior of the vehicle can get too warm even if the outside temperature is below 60°F. Also, more and more vehicles (12% for 1997 vehicles) have automatic temperature controls. Even with the heater "on" such systems will activate the A/C to de-humidify the air which eliminates fog buildup on the inside of the windshield.

In an attempt to learn how the current emissions models treat A/C use, CAVTC reviewed information on EPA's Mobile 5b emissions model. The users guide for the Mobile 5b emissions model provided guidance regarding this model's ability to reflect vehicle A/C use. While noting that the basic emission rates in Mobile 5b already include additional loadings intended to simulate the use of A/C, they also stated that "The additional air conditioning correction factors that are calculated in Mobile 5b are of uncertain accuracy."

To test Mobile 5b's sensitivity to A/C use, CAVTC ran two model cases with a maximum temperature of 95º F and 40% relative humidity. The only difference between the two runs was that one case was run with the A/C "on" and the other test was run with it the A/C "off." The composite oxides of nitrogen (NO_x) emission rates for LDV and LDT from these model tests, and the corresponding change in emissions with A/C "on", are shown in Table 1.

Table 1

Composite EPA Mobile 5b NO_x Emission Rates (gr/mi)

	Air Conditioning Off	Air Conditioning On	Change
LDV	1.465	1.543	+5.3%
LDT	1.680	1.656	-1.4%

The changes in the NO_x emissions as a result of A/C use (+5.3% and –1.4%) are insignificant, being substantially below what would be expected. (The incorporation of a dedicated A/C test cycle in the supplemental FTP regulations – the SC03 – reflects the concern over the effects of A/C use.) EPA and ARB are fully aware of the inability of the current emissions models to account for A/C operation. Both agencies are actively involved in revising their emissions models to better reflect air-conditioning effects as well as other driving and technology factors.

Previous Work Done to Examine Air-Conditioning Impacts

ARB recently tested ten vehicles to examine the effects of A/C use on vehicle emissions. Using the Unified Cycle, test vehicles were tested under two different conditions:[1]

1. A/C "off", but with an extra 10% road load horsepower to account for the additional power drain on the engine when A/C is in use.

2. A/C "on", but with *no* extra road load.

All tests were conducted at 75º F. The change in the "mean" Bag 2 emissions for these tests are presented in Table 2. Note that Bag 2 emissions are used by ARB to better represent the emissions effects as they correspond to a stabilized driving condition.

[1] The Unified Cycle (UC) – also referred to as the LA-92 – is a driving cycle that is more representative of "real world" driving and emissions than the standard Federal Test Procedure (FTP) which is used for vehicle emissions certification purposes. NO_x and carbon monoxide (CO) emissions for the UC cycle are typically higher than the FTP emissions. Two other driving cycles are used in this project: 1) the SC03 which is a specific air-conditioning test cycle, and 2) the IM240 which is a 240 second cycle used for inspection and maintenance (I&M) tests which are performed on a dynamometer.

Table 2

Percent Change in Mean Emissions
With Air-Conditioning “On” vs. Air Conditioning “Off”
(Unified Cycle @75° F)

HC	CO	NO_x	CO_2
+13%	+56%	+26%	+10%

Source: ARB memorandum – Development of Air Conditioning Emissions Factors, August 26, 1998.

ARB’s work clearly demonstrates that A/C use can significantly increase CO, NMHC, and NOx emissions even under modest environmental conditions. At higher temperature, humidity, and solar conditions, the A/C impacts are likely to become even more dominant.

Objective

The primary objective of this project was to evaluate and characterize the impact of A/C use on tailpipe emissions for in-use vehicles. Previous – albeit limited – tests have shown that A/C use can have a significant impact on vehicle emissions. But more testing was required to better understand these effects.

To satisfy this objective, a comprehensive testing protocol was developed and used in this project. In total, more than 198 tests were performed of 14 light-duty vehicles. The outcome of this work is a large emissions database, which characterizes how A/C use impacts vehicle emissions under a variety of test conditions including multiple driving cycles, varying temperature, humidity, and solar load settings, and different fuels. The information gained from this project will help to identify how non-vehicle factors affect the A/C impacts, and will also be valuable in terms of identifying the focus and scope of future air-conditioning impact studies.

Application of Project Results

It is expected that the findings from this and subsequent air-conditioning impact projects will be used to develop “air-conditioning use” adjustment factors that will be integrated into new emission inventory models. The database developed in this project will also help in understanding the interactions between the vehicle emissions and various operating and environmental factors.

Section III

METHODOLOGY

This section will describe the test program and procedures.

Test Protocol

This project actually included two distinct test protocols. The "core" protocol – which was funded by CRC and ARB – consisted of 12 tests. This protocol included:

- Four different driving cycles:
  - EPA-75
  - SC03
  - Unified
  - IM240
- Two test temperatures:
  - 75° F
  - 95° F
- Three humidity conditions:
  - 100 grains water/lb. dry-air
  - 75 grains water/lb.dry-air
  - Ambient levels (uncontrolled)
- Two solar-load conditions:
  - 850 watts per square meter
  - No solar load
- Two air-conditioning operating conditions:
  - A/C "on"
  - A/C "off"

All vehicles involved in the project underwent the core test protocol. For the core protocol, the test fuel used was California Phase 2 gasoline.

In addition to the core protocol, a "supplemental" protocol funded by Texas Natural Resources Conservation Commission (TNRCC) was added to the project. This protocol, which consisted of six additional tests, was designed to address test conditions that were specifically relevant to the state of Texas. Only six of the 14 vehicles used in the project were tested using the TNRCC protocol.

This protocol component involved performing the EPA-75 and SC03 cycles with additional test conditions.

- Two different test fuels:
  - Federal reformulated gasoline
  - Industry-average non-reformulated gasoline
- Two test temperatures:
  - 95º F
  - 105º F

Table 3 provides a summary of all the tests performed in this project. This table, which includes both the core and TNRCC protocols, identifies the combinations of drive cycles and test conditions used for each test. Tables 4 and 5 show the sequencing of the individual tests for both the core and TNRCC test protocols, respectively.

All tests performed – excluding the EPA-75 – were hot-start tests. Preconditioning sequences for the EPA-75 and SC03 tests were conducted in accordance with the Federal test procedures, except in those cases where the test temperature, humidity level, or solar load conditions were modified. For any non-standard test, the preconditioning sequence was performed under the same temperature, humidity, and solar load conditions as specified for the scheduled test. That is, if an SC03 was to be run at 75º F, a humidity level of 50 grains of water/lb. dry air control, and no solar load, the preconditioning sequence would be run under the same conditions.[2]

Note that the SC03 test procedure stipulates that a ten minute soak be performed between the preconditioning cycle and the actual test, and a similar soak between subsequent SC03 tests. This soak was performed under the same environmental conditions as test cycle condition. Soaks, however, were not used for non-SC03 tests.

[2] Note that at the start of the program, the humidity level for the FTPs and the SCO3s run at 75º F was not controlled but was run at ambient conditions. Midway through the program, a change was made to control humidity at 50 grains of water for these same tests.

TABLE 3: SUMMARY OF TESTS PERFORMED:
A/C TEST CONDITIONS vs. DRIVE CYCLE

CORE TESTS

TEST CYCLE	TEST GASOLINE	A/C STATUS ON	A/C STATUS OFF	TEST TEMP 75 F	TEST TEMP 95 F	TEST TEMP 105 F	HUMIDITY CONTRL	SOLAR LOAD USE
FTP	Calif. Phase 2		OFF	75			50 GR*	NO
FTP	Calif. Phase 2	ON			95		50 GR*	NO
FTP	Calif. Phase 2	ON		75			50 GR*	NO
SCO3	Calif. Phase 2		OFF	75			50 GR*	NO
SCO3	Calif. Phase 2	ON		75			50 GR*	NO
SCO3	Calif. Phase 2		OFF		95		100 GR	YES
SCO3	Calif. Phase 2	ON			95		100 GR	YES
								YES
SCO3	Calif. Phase 2	ON			95		100 GR	YES
UC	Calif. Phase 2		OFF		95		75 Gr	NO
UC	Calif. Phase 2	ON			95		75 Gr	NO
IM 240	Calif. Phase 2	ON			95		75 Gr	NO
IM 240	Calif. Phase 2		OFF		95		75 Gr	NO

*NOTE: The first seven vehicles were tested using the ambient humidity level, while the last seven vehicles were tested using a controlled humidity level of 50 grains of water.

TNRCC TESTS

TEST CYCLE	TEST GASOLINE	A/C STATUS ON	A/C STATUS OFF	TEST TEMP 75 F	TEST TEMP 95 F	TEST TEMP 105 F	HUMIDITY CONTRL	SOLAR LOAD USE
FTP	*Non-RFG Gasoline*		OFF	75			50 GR	NO
FTP	*Fed RFG Gasoline*		OFF	75			50 GR	NO
SCO3	*Non-RFG Gasoline*	ON			95		100 GR	YES
SCO3	*Non-RFG Gasoline*	ON				105	100 GR	YES
SCO3	*Fed RFG Gasoline*	ON			95		100 GR	YES
SCO3	*Fed RFG Gasoline*	ON				105	100 GR	YES

TABLE 4: CORE TEST PROTOCOL

DAY	TEST	TEST SEQ	A/C STATUS ON	A/C STATUS OFF	TEST TEMP 75 F	TEST TEMP 95 F	TEST TEMP 105 F	HUMIDITY CONTROL	SOLAR LOAD USE
#1	Process Vehicle, Fuel w/ **Cal Phase II Gasoline**								NO
#2	FTP	1		OFF	75			NO/50 GR	NO
	SCO3	2		OFF	75			NO/50 GR	NO
	SCO3	3	ON		75			NO/50 GR	NO
#3	FTP	4	ON			95		NO/50 GR	NO
	SCO3	5	ON			95		100 GR	YES
	SCO3	6	ON			95		100 GR	YES
	SCO3	7		OFF		95		100 GR	YES
#4	FTP	8	ON		75			NO/50 GR	NO
	UC	9		OFF		95		75 Gr	NO
	UC	10	ON			95		75 Gr	NO
	IM 240	11	ON			95		75 Gr	NO
	IM 240	12		OFF		95		75 Gr	NO
	Drain & Fill w/ **Non-RFG Gasoline**								

TABLE 5: TNRCC TEST PROTOCOL

DAY	TEST	TEST REP	A/C STATUS ON	A/C STATUS OFF	TEST TEMP 75 F	TEST TEMP 95 F	TEST TEMP 105 F	HUMIDITY CONTROL	SOLAR LOAD USE
#5	FTP w/ **Non-RFG Gasoline**	13		OFF	75			50 GR	NO
	SCO3	14	ON			95		100 GR	YES
	SCO3	15	ON				105	100 GR	YES
	Drain & Fill w/ **Fed RFG Gasoline**								
#6	FTP w/ **Fed RFG Gasoline**	16		OFF	75			50 GR	NO
	SCO3	17	ON			95		100 GR	YES
	SCO3	18	ON				105	100 GR	YES
	De-Prep Vehicle								

The preconditioning sequence for the Unified Cycle consisted of running the vehicle for five minutes at 50 miles/hour. At the end of the 5-minute preconditioning, the vehicle immediately started the test cycle without a key-off event. The IM240 preconditioning consisted of running the vehicle for five minutes at 50 miles/hour. At the end of the five-minute warm-up, the test cycle was started using a key-start.

Test Repetitions

Due to budget constraints, emphasis was placed on conducting a comprehensive test protocol, rather than performing repetitions for each test condition. As a consequence – with one exception – only one test was run for each test cycle/test condition combination. The exception was in performing the actual SC03 certification test (i.e., SC03 drive cycle, 95º F temperature, 100 grains water, full solar load, and A/C on). For this case, two tests were run back-to-back.

Exhaust Emission Measurements

In the course of conducting this project the following exhaust emissions were measured:

- Total Hydrocarbons (THC)
- Methane (CH_4)
- Non-Methane Hydrocarbons (NMHC)
- Oxides of Nitrogen (NO_x)
- Carbon Monoxide (CO)
- Carbon Dioxide (CO_2)

For each test, bag-dilute emission data were analyzed and recorded. In addition, for test sequence numbers 5, 6, and 7 shown in Table 4 (SC03s at 95º F, 100 grains plus solar load), tailpipe second-by-second “raw” emissions data were also recorded.

Test Equipment

All vehicle tests performed for this project were conducted in CAVTC's Test Cell II. Test Cell II consists of an environmental enclosure with full temperature and humidity controls. This test cell offers the following features and test capabilities:

- 48" single roll electric dynamometer
- Computerized 4-bay exhaust analysis bench (i.e., bag dilute plus pre-, mid-, and post-catalyst raw emissions capability)
- Full HC speciation
- Fully programmable drive cycle selection
- FTP, SFTP (i.e., US06 and SC03), and custom cycle test capabilities including a 6 phase CVS
- True running loss evaporative emissions measurement (not used for this project)

Figures 1 and 2 show an external and internal view of the environmental enclosure/test cell where the testing was performed. Figure 2 also shows the solar lamp array system installed in the enclosure which was used to simulate the solar load.

Dynamometer road load horsepower (RLHP) values were derived from vehicle certification data obtained from ARB. These data were then used to derive test values for the 48" electric dynamometer.

Test Fuels

All test fuels used in this program were obtained from Phillips Petroleum in Texas. The key characteristic of each test fuel is shown in Table 6. Appendix A contains the Certificate of Analysis for each test fuel which provides comprehensive data on the fuel composition.

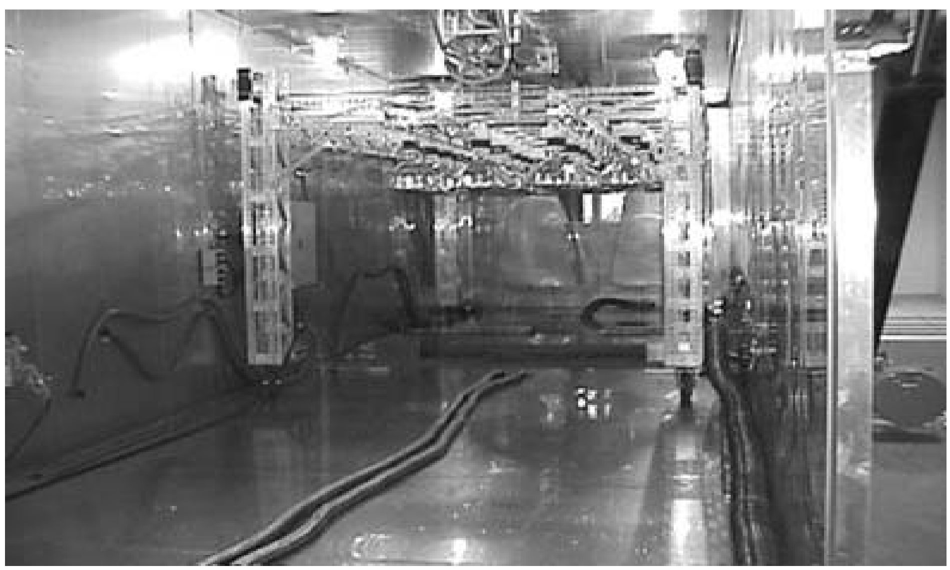
Table 6

Test Fuels

Control Number	Category	Carbon Weight	Oxygen Weight	Specific Gravity	Heating Value	Description
W-658-B	RFA	.8583	.0000	.748	18,431	Federal non-reformulated
D-817A	RFG	.8352	.0208	.742	18,522	Federal reformulated
D-611	PH2	.8352	.0200	.739	18,549	California Phase 2 reformulated
D-646	PH2	.8348	.0200	.737	18,553	California Phase 2 reformulated

Figure 1

Figure 2



Test Vehicles

Test Vehicle Composition:

Fourteen California emission-certified vehicles were tested during this project. CRC had specified that the vehicles be split into two general technology groupings as characterized by model-year.

- Model Years 1995-1997
- Model Years 1985 – 1988

Two additional vehicle procurement goals were established: 1) the test vehicles should include light-duty trucks as well as passenger cars; and 2) similar vehicle models should be used – to the extent possible – for both model-year groupings.

Table 7 shows the composition of the test fleet.

Table 7

Test Vehicles

Model Years '95-'97	Model Years '85-'88
Ford Taurus – '97	Ford Taurus* – '87
Honda Civic – '95	Honda Civic – '86
Plymouth Voyager – '95	Plymouth Voyager* – '88
Toyota Camry – '97	Toyota Camry – '86
Chevrolet Camaro – '96	Chevrolet Camaro* – '85
Buick Skylark* – '95	Oldsmobile Cutlass* – '86
Ford F-150* – '95	Ford F-150 – '86

**These vehicles were used for the TNRCC protocol*

The TNRCC program element was to include five test vehicles. However, since there was a mistake in performing the two FTP tests on the first TNRCC vehicle – the FTPs using the RFA and RFG fuels were performed with the A/C "on" instead of "off" – a sixth test vehicle was added. The SC03 tests for this vehicle are still valid and are included in the test results shown later.

Detailed information, including the mileage, engine type/size, transmission type, and vehicle's test weight are shown in Table 8. It should be noted that none of the vehicles tested were equipped with automatic temperature controls, but instead had manual temperature controls. (Additional vehicle information and the parameters used to develop the 48" dynamometer settings are available in the project's database described in Section IV.)

Test Vehicle Procurement:

The test vehicles used for this project were obtained from several sources including:

- Rental companies
- Used car lots
- Private fleets
- Classified advertisements
- Direct owner contacts / solicitations
- Personal references and bounties

Test Vehicle Processing:

Once a potential vehicle was identified, background information on the vehicle was checked, if available. If the vehicle was determined to be suitable, the vehicle was inspected to insure that it could be safely operated. In cases where the vehicle was deemed unsafe, it was rejected.

Table 8

Test Vehicle Information

MAKE/MODEL	MODEL YEAR	MILEAGE	ENGINE TYPE	TRANS. TYPE	INERTIA
Ford Taurus	1997	33,000	3.0L V-6	A-4	3625
Ford Taurus	1987	65,800	2.5L I-4	A-4	3625
Honda Civic	1995	45,270	1.5L I-4	M-5	2750
Honda Civic	1986	105,641	1.5 L I-4	M-5	2375
Plymouth Voyager	1995	48,515	3.0L V-6	A-4	3875
Plymouth Voyager	1988	145,081	3.0L V-6	A-4	3875
Toyota Camry	1997	28,215	3.0L V-6	A-4	3500
Toyota Camry	1986	181,518	2.0L I-4	A-4	2750
Chevrolet Camaro	1996	33,227	5.7L V-8	A-4	3750
Chevrolet Camaro	1985	128,694	5.0L V-8	A-4	3750
Buick Skylark	1995	65,247	3.lL V-6	A-4	3250
Oldsmobile Cutlass	1986	106,395	5.0L V-8	A-4	3750
Ford F-150	1995	32,347	5.8L V-8	A-4	5500
Ford F-150	1986	100,022	5.0L V-8	A-4	4000

Additional information on the test vehicles including fuel system type and their corresponding certification emissions standards are shown in Appendix B.

Note that all vehicles were tested as received. Generally, no attempt was made to tune the vehicles or to replace mechanical parts. Corrective measures were taken, however, in cases where the vehicle's A/C system was inoperable. For the MY '85-'88 vehicles, it was generally necessary to replace air-conditioning system hoses or fittings, and/or to recharge the system prior to initiating testing. Fluid and or exhaust leaks were also fixed, where possible, to avoid potential safety problems.

In addition, thermocouples were installed in the fuel tank of each test vehicle. This was required in order to monitor the fuel temperature.

It should also be noted that three additional vehicles that were procured were subsequently dropped from the program because there was a concern about the safety of personnel and equipment.

Incentives:

In exchange for the use of a vehicle, owners were provided a $200-250 cash incentive, a loaner vehicle, free fuel, and other inducements as necessary. In the case of rental cars, the agency was paid their normal fees.

Test Procedures

Test Sequencing:

In performing the emissions tests, the testing sequence used for each vehicle was unchanged, with few exceptions. All vehicle tests were done in accordance with the test protocols shown in Tables 3 and 4. If there was a problem in running a test within a specific test group (i.e., a series of tests involving the same test cycle, but different A/C and/or environmental conditions), the entire test group was repeated as a unit.

As an additional control and to the extent possible, the same driver was used to operate a specific test vehicle through the entire test sequence. This was done to eliminate the driver as a variable.

Fueling:

Periodically, it was necessary to add fuel to a test vehicle during the course of the day's testing. This was only done as necessary. Refueling was typically done for one of two reasons: 1) the temperature of the fuel in the vehicle's tank was approaching the maximum threshold; the objective was to keep the temperature of the fuel in the tank below 130º F, or 2) a fuel change was dictated by the FTP test procedure.

As the test team gained experience with controlling fuel tank temperature, intermediate refueling became less common.

Monitoring Test Conditions:

During the course of performing the test sequence, key test conditions were tracked on a continual basis. The primary test parameters measured, recorded, and monitored were:

- Test chamber temperature
- Test chamber humidity
- Fuel temperature (inside the tank)

In addition to these real-time measurements, the solar load system was checked to ensure that the vehicle-specific solar intensity and distribution were in compliance with the test requirements. The primary element of the solar load that needed to be checked was achieving the appropriate intensity at the base of the front and rear windshield along the centerline of the vehicle.

Note that A/C clutch engagement and other A/C functions were not monitored in this project.

Timing:

The core protocol required approximately four days to complete. This time could be extended by 1-2 days depending on when the vehicle was received and how much work was required to make the A/C system functional. The TNRCC protocol added an extra two days. Allowing for weekends, the typical vehicle was required for 7-10 days

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Section IV

RESULTS AND FINDINGS

Key Results

The key results of this project are summarized below:

1. Vehicle exhaust emissions increase significantly with the use of air conditioning.

2. Fuel economy decreases with air-conditioning use.

3. The effects of A/C use on emissions and fuel economy are sensitive to the:[3]
   - Vehicle
   - Ambient environment

Tables 7, 8, and 9 illustrate how A/C use impacts the emissions and fuel economy for the two model-year (MY) vehicle groupings used in this project -- MY '95-'97 and MY '85-'88 vehicles – and for the combined test fleet. The results shown in Tables 7-9 represent the average change in emissions and fuel economy that result when operating vehicles with the A/C "on" compared to operating the same vehicles with the A/C "off." Separate tables are provided for each vehicle grouping. Each table examines the emissions and fuel economy changes for five unique test conditions which incorporate different driving cycles, temperatures, humidity levels, and solar load. The results shown in Tables 7-9 are expressed in both absolute and percentage terms.

It should be noted that for the absolute – or "g/mi" – values presented in Tables 7-9 are statistically significant unless otherwise identified. A value was considered statistically significant if the significance level was equal to or less than 0.05.

In contrast to the absolute values shown in Tables 7-9, it was not possible to determine the statistical significance of the "percentage" changes shown in

[3] There also appears to be a difference in the emissions and fuel economy as a function of the driving cycle used, however, no specific statistical analyses were conducted to verify this observation.

these tables. No confidence intervals were calculated because the formulas for the confidence limits of percentage changes are based on large samples. The formulas can be very imprecise when small data sets are used, as was the case for this project.

Table 7

Emissions and Fuel Economy Impacts of Air Conditioning Use
Model Years '95-'97 Vehicles

(g/mi, mi/gal, and % increase or decrease for A/C "On" vs. "Off")

	Test Condition			CO		NOx		NMHC		MPG	
Drive Cycle	Temp	Gr H_20	Solar Ld	g/mi	%	g/mi	%	g/mi	%	mi/gal	%
EPA-75	75 F	50	Off	0.557	43%	0.156	68%	0.0169 #	27%	-2.817	-14%
SC03	75 F	50	Off	0.756 #	55%	0.145	50%	0.018	33%	-3.772	-17%
SC03*	95 F	100	**On**	1.626	71%	0.189	81%	0.015 #	30%	-4.604	-22%
Unified	95 F	75	Off	3.794 #	234%	0.130	37%	0.062 #	186%	-3.211	-18%
IM 240	95 F	75	Off	0.392 #	27%	0.206	60%	0.022 #	45%	-3.535	-16%

Notes: # Denotes result "**not**" statistically significant.
*****Result is average of the two SC03 tests runs.

Table 8

Emission and Fuel Economy Impacts of Air Conditioning Use
Model Years '85-'88 Vehicles

(g/mi, mi/gal, and % increase or decrease for A/C "On" vs. "Off")

	Test Condition			CO		NOx		NMHC		MPG	
Drive Cycle	Temp	Gr H_20	Solar Ld	g/mi	%	g/mi	%	g/mi	%	mi/gal	%
EPA-75	75 F	50	Off	1.755	19%	0.379	35%	-0.005 #	-1%	-2.266	-11%
SC03	75 F	50	Off	3.554	33%	0.578 #	40%	0.021 #	3%	-3.067	-14%
SC03*	95 F	100	**On**	5.401	30%	0.540	46%	0.131 #	17%	-3.962	-19%
Unified	95 F	75	Off	1.934 #	11.2%	0.655	37%	0.043 #	7%	-2.443	-14%
IM 240	95 F	75	Off	1.418 #	18%	0.479	31%	0.208 #	32%	-2.631	-13%

Notes: # Denotes result "**not**" statistically significant.
*****Result is average of the two SC03 tests runs.

Table 9

Emission and Fuel Economy Impacts of Air Conditioning Use
Combined Fleet of Test Vehicles

(g / mi, mi / gal, and % increase or decrease for A / C "On" vs. "Off")

	Test Condition			CO		NOx		NMHC		MPG	
Drive Cycle	**Temp**	**Gr H_20**	**Solar Ld**	**g/mi**	**%**	**g/mi**	**%**	**g/mi**	**%**	**mi/gal**	**%**
EPA-75	75 F	50	Off	1.202	28%	0.276	47%	0.005 #	8%	-2.520	-13%
SC03	75 F	50	Off	2.155	35%	0.362	41%	0.019 #	5%	-3.420	-16%
SC03*	95 F	100	**On**	3.514	35%	0.364	51%	0.073 #	18%	-4.283	-20%
Unified	95 F	75	Off	2.864	30%	0.392	37%	0.052 #	15%	-2.827	-16%
IM 240	95 F	75	Off	0.905 #	19%	0.342	36%	0.115 #	33%	-3.083	-14%

Notes: # Denotes result "**not**" statistically significant.
*****Result is average of the two SC03 tests runs.

The results shown in Tables 7-9 were obtained from a series of reports prepared by Professor Richard Gunst. These reports, " CRC Project No. E-37, The Effects of Air Conditioning on Regulated Emissions from In-Use Vehicles: Mean Emissions and Fuel Economy Comparisons," consist of seven different statistical analyses. This report series presents a detailed statistical analysis of all the project data and is available through CRC.

The statistical analysis investigated the effects of several other factors on emissions and fuel economy. One comparison was the effect of temperature (A / C "on," no solar load, FTP cycle). Statistical significant differences were observed between tests run at 75º and 95º F—CO and NO_x increased and fuel economy decreased for old cars, new cars, and the combined car categories with increasing temperature.

There were minimal statistically significant results from the special protocols that utilized both RFG and RFA fuels (TNRCC sponsored tests). The lack of statistical significance was primarily due to the reduced number of vehicles that were tested in this phase. In addition, the variability of results were very high at the highest temperature setting (105ºF). There were indications that CO was reduced with the use of oxygenated fuels (RFA vs. RFG). With the Unified Cycle (A / C "on," no solar load, and 95º F) the CO reductions were statistically significant for two of the three car categories—old cars and all cars—due to the use of RFG.

As a frame of reference, Table 10 shows the average emissions and fuel economy values for the two MY groupings, and for the combined test fleet. The values shown are for the conventional EPA-75 test. As expected, the MY '95-'97 test fleet typically had lower absolute emissions than the MY '85-'88 fleet, yet similar fuel economy.

Table 10

Average Emission Values – EPA-75 @75° F A/C Off

	CO (g/mi)	NO_x (g/mi)	NMHC (g/mi)	MPG (mi/gal)
7 Model-Year '95-97 Vehicles	1.64	0.28	0.11	20.40
7 Model Year '85-'88 Vehicles	9.44	1.09	0.77	19.83
All 14 Vehicles Combined	5.54	0.69	0.44	20.11

Detailed Test Results

Appendix C provides a series of figures which show how the individual test vehicle emissions and fuel economy changed as a function of the test cycle and test conditions. Each set of figures consists of eight plots. The first four plots provide data on the CO, NO_x, and NMHC emissions plus fuel economy values for each individual vehicle in the MY '95-'97 grouping. The second four plots provide the same data but for the MY '85-'88 grouping. The four series of figures included in Appendix C include:

1. EPA-75 cycle vehicle emissions and fuel economy for the following conditions:

- 75º F, A/C "off", Phase 2 gasoline
- 75º F, A/C "on", Phase 2 gasoline
- 95º F, A/C "on", Phase 2 gasoline

2. SC03 cycle vehicle emissions and fuel economy for the following conditions:

- 95º F, solar load, humidity control, A/C "off", Phase 2 gasoline
- 95º F, solar load, humidity control, A/C "on", Phase 2 gasoline

3. Unified cycle vehicle emissions and fuel economy for the following conditions:

- 95º F, humidity control, A/C "off", Phase 2 gasoline
- 95º F, humidity control, A/C "on", Phase 2 gasoline

4. SC03 cycle vehicle emissions and fuel economy for the following conditions:

- 95º F, Phase 2 gasoline
- 95º F, Non-reformulated gasoline
- 105º F, Non-reformulated gasoline
- 95º F, Federal reformulated gasoline
- 105º F, Federal reformulated gasoline

In addition, Appendix D presents two additional series of figures which provide graphical displays of the test results that are specifically related to the TNRCC protocol. These figures cover:

1. SC03 cycle vehicle emissions and fuel economy for the following conditions:

- 95º F, A/C "on", Federal reformulated gasoline
- 95º F, A/C "on", Non-reformulated gasoline
- 105º F, A/C "on", Federal reformulated gasoline
- 105º F, A/C "on", Non-reformulated gasoline

2. EPA-75 cycle vehicle emissions and fuel economy for the following conditions:

- 75º F, A/C "off", Phase 2 gasoline
- 75º F, A/C "off", Federal reformulated gasoline
- 75º F, A/C "off", Non-reformulated gasoline

Test Data

A vast quantity of data was collected in the course of conducting this project. As previously mentioned, more than 198 individual test were performed. Consequently, only selected data have been presented in this report.

To augment this report, a compact disk containing the detailed test data and test parameters will be provided as a separate deliverable. This will allow serious practitioners to conduct their own analysis of the results. The organization of this database is included on the disk.

Implications for Future Emissions Model

ARB and EPA are fully aware that their current emissions models do not adequately account for the emissions increases that are associated with the use of vehicle A/C systems. In an effort to better reflect air conditioning effects, ARB is developing A/C correction factors. EPA is also planning to incorporate improved A/C factors in the next version of their model, Mobile 6.

Technical Challenges Encountered

In starting this test project, CAVTC encountered several technical challenges that were related to conducting the SC03 test in accordance with the federal test regulations. CAVTC had designed and installed individual systems to match these requirements, but found that making the individual components work as an integrated system was more complex than expected. The problems encountered and resolved are summarized below:

Solar Load: CAVTC designed and built the solar load system that was used throughout this program. A lighting engineer assisted in specifying and identifying the type, quantity, and configuration of lights that would work effectively in our environmental chamber. It wasn't until the solar system was installed and integrated with the enclosure that it was discovered how difficult it was to achieve the required distribution of lighting intensity for various size vehicles, while at the same time being able to satisfy the light intensity values at the base of the front and rear windshields along the centerline of the vehicle. After several iterations and modifications to the solar load system, we were able to meet the requirements. This process was iterative and time-consuming. It also resulted in increasing the total amount of lighting by 50%.

Humidity Control: A specially designed humidity control system was also installed in the enclosure. Its function was to attain the specified humidity level within the enclosure over a broad range of conditions. What worked well in an empty enclosure became a big challenge once the vehicle was installed and the solar load was in use. Maintaining a uniform humidity level within the enclosure was another challenge, and was exacerbated by the changes made to the fan (to be discussed later) that was part of the SC03 requirements. Again, by modifying the humidity control and operation along with other adjustments to the test system, these problems were resolved.

Fan: The SC03 test requirements – which dictated the overall functional specifications for the testing environment – also included a variable speed fan that increased air flow in proportion to the vehicles' speed. A key element of the fan specification that needed attention was that the flow of air must be laminar, not turbulent. Further, a requirement of the SC03 test involves achieving a wind velocity that is proportional to the area of the fan's outlet. This required construction of a shroud for the round fan that directed the air flow through straighteners to achieve the proper volume of laminar flow. Again, achieving this involved several iterations.

Drivers' Monitor: The intensity of the solar load made it very difficult for the test vehicle driver to use the normal driver's aid monitor. To resolve this problem, an in-car screen was used. While this was not a big challenge, it was not anticipated and required that a modification to the standard procedures be implemented.

Operational Challenges and Test Anomalies

The most difficult operational challenge encountered – with the exception of the driver's discomfort—was keeping the fuel tank temperature below 130º F. Initially, violation of this requirement was the cause for several aborted tests. While a system for blowing cool air onto the gasoline tank was used, it was not always effective. An interim fix that was employed involved adding cool-temperature fuel to the gasoline tank after running a couple of tests. This was effective, but time consuming. Eventually, effective control of the fuel tank temperature was achieved through changes in our test procedures. As with most situations, as the project team gained experience with these complex tests, they gained proficiency in conducting the tests.

Finally, anomalous results would occur periodically – results that were difficult to explain. The primary test result that was difficult to interpret was the second test in a series of – back-to-back SC03 tests run at 95º F, with solar load, and with humidity controlled to 100 grains of water / pound of dry air. While half of the tests results showed good repeatability, the other half would have an extreme result, even though the fuel temperature was kept in control. Lacking a reasonable explanation for this situation, we chose to use the average results for the two tests in the presentation of our findings. The results of the individual tests, however, are included in the comprehensive database contained on the enclosed compact disk.

Acknowledgements

CAVTC wants to thank both Harold Haskew and Steve Welstand for their advice, support, and encouragement in setting-up our test system, educating the CAVTC staff, and making this exciting and challenging project a success. Their involvement was invaluable.

NOTE: In a parallel effort, Professor Richard Gunst has conducted a statistical analysis of the A/C program test data, and prepared a series of task reports which address the statistical significance of various findings. This series of results are available through CRC.

BKI data/cavtc/CRC Final 3-99/Steve Welstand 10-14-99/CRC Final Report

11/3/99