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FEDERAL TEST PROCEDURE AND SHORT TEST CORRELATION ANALYSES

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Mobile Source Air Pollution Control
Emission Control Technology Division
Ann Arbor, Michigan 48105

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FEDERAL TEST PROCEDURE AND SHORT TEST CORRELATION ANALYSES

by

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FOREWORD

This report, prepared by The Aerospace Corporation for the U.S. Environmental Protection Agency, Emission Control Technology Division, presents the results of a statistical analysis of the degree of correlation between five short tests and the 1975 Federal Test Procedure. The correlation analyses were based on experimental test data from 147 1974-model-year vehicles, composed of three inertia test weight groups, and on 40 catalyst-equipped experimental vehicles.

The results of the study are presented in six sections. Section 1 contains a summary of the study results. The background, scope, objectives, and method of approach are given in Section 2. The short tests, test conditions, and test fleet composition are described and discussed in Section 3. Section 4 describes the data-screening procedures, the primary statistical tools used in the correlation analyses, and results of the statistical analysis in detail for the catalyst-equipped experimental vehicle fleet. Similar results for the 1974 model year in-use fleet and a five-vehicle defect test fleet are presented in Sections 5 and 6, respectively.

The conduct of this analysis effort resulted in over 1000 pages of correlation table printouts, regression plots, scattergrams, etc. This information is summarized in the tables and figures presented in the report; the voluminous printout material is not included in order to enhance the readability of the report. However, the printout material is on file at the Emission Control Technology Division of EPA, Ann Arbor, Michigan, and may be borrowed for limited periods for reproduction for purposes of detailed examination.

ACKNOWLEDGMENT

During the course of this study, Mr. F. P. Hutchins of the Environmental Protection Agency's Emission Control Technology Division, who served as EPA Project Officer for the study, provided valuable guidance and assistance. His efforts are gratefully acknowledged.

Dr. John Thacker was principally responsible for the statistical analysis effort reported herein. The following technical personnel of The Aerospace Corporation also made valuable contributions to the analyses performed under this contract:

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1. SUMMARY

1. SUMMARY

A series of statistical analyses was performed to determine the degree of "correlation" that exists between five specific short tests (STs) and the federal emission certification test procedure (FTP) for new vehicles. This work was performed to determine if "reasonable correlation with certification test procedures" exists; this is a condition precedent to the promulgation of regulations that impose the in-use warranty provisions of Sec. 207 (b) of the Clean Air Act of 1970 upon the motor vehicle manufacturers.

The basis for the analyses was ST and FTP test data from three vehicle fleets:

- A catalyst-equipped experimental vehicle fleet (40 vehicles)
- An in-use 1974 model year vehicle fleet (147 vehicles)
- A catalyst-equipped defect test fleet (5 vehicles)

Each of the vehicles in these fleets was tested by the FTP and the following STs:

- Federal Short Cycle
- New York/New Jersey (NY/NJ) Composite
- Clayton Key Mode
- Federal Three-Mode
- Unloaded 2500 rpm

The first two of these STs are CVS (constant volume sampling) or bag-type tests wherein a test technician drives the car on the dynamometer in accordance with a prescribed driving pattern. The vehicle exhaust is diluted by the CVS procedure, and a single sample bag of diluted exhaust is collected for the ST. The latter three STs are categorized as modal or volumetric. In these tests, the test technician operates the vehicle on a dynamometer at a fixed vehicle speed and dynamometer load, or unloaded at a fixed engine rpm, or at idle. The vehicle tailpipe exhaust is sampled directly, and the concentration of each pollutant is measured and recorded. The Clayton Key Mode and the Federal Three-Mode STs each have high-speed, low-speed, and idle modes. The Unloaded 2500 rpm ST is a high-speed test with the transmission in neutral at 2500 engine rpm.

Hydrocarbon (HC) and carbon monoxide (CO) measurements were recorded with both laboratory analyzers and garage-type instruments for most of the volumetric tests (Key Mode, Federal Three-Mode, Unloaded 2500 rpm). All oxides of nitrogen (NO_x) measurements were made with laboratory analyzers.

Two different statistical analysis methods were used to assess "correlation" -- a conventional correlation analysis, and a contingency table analysis.

The principal results of the study are summarized in the following sections. Because of the many variables involved (three test fleets, five STs, three emission constituents, two types of measurement instruments, etc.), the results are presented first as a function of fleet type; then overview statements or findings are presented which provide more general conclusions, where appropriate.

1.1 CATALYST-EQUIPPED EXPERIMENTAL VEHICLE FLEET

1.1.1 Direct Relatability Results

A conventional correlation analysis was performed for the catalyst-equipped vehicle (CEV) fleet for each of the five short tests; a summary of the ST/FTP correlation coefficients obtained is given in Table 1-1. The correlation coefficient (r) is the quantitative measure of relatability between the results of the short test and the FTP. The closer r is to 1, the better the relation. No relationship is indicated by r = 0. Negative r indicates an inverse relation between the observed test results. For a test sample size (N) of 40 or 39, a computed correlation of less than 0.35 indicates that the ST and the FTP pollutants are uncorrelated with 95 percent confidence. For N = 25 or 26, this threshold is approximately 0.4.

Table 1-1. ST/FTP Correlation Summary (CEV Fleet)

Short Test	Good Data Set[a]	Test Mode	N[b]	"r"-ST/FTP Correlation[c] Coefficient		
				HC	CO	NO_x
Federal Short Cycle	First		39	0.87	0.81	0.62
	Second		25	0.91	0.42	0.47
	Average		39	0.93	0.83	0.53
NY/NJ Composite	First		39	0.92	0.77	0.61
	Second		25	0.92	0.71	0.51
	Average		40	0.95	0.68	0.61
Key Mode (Laboratory)	First	High	40	0.61	0.26*	0.79
		Low		0.53	0.39	0.20*
		Idle		0.92	0.54	0.27*
	Second	High	26	0.57	0.30*	0.86
		Low		0.53	0.31*	0.04*
		Idle		0.97	0.40	0.04*
Key Mode (Garage)	First	High	40	0.73	0.37	
		Low		0.73	0.21*	
		Idle		0.88	0.52	
	Second	High	26	0.51	0.08*	
		Low		0.39*	0.09*	
		Idle		0.32*	-0.03*	
Federal Three-Mode (Laboratory)	First	High	31	0.87	0.08*	0.89
		Low		0.79	0.22*	0.03*
		Idle		0.80	0.48	0.13*
	Second	High	26	0.68	0.20*	0.92
		Low		0.52	0.27*	-0.28*
		Idle		0.94	0.34*	0.08*
Federal Three-Mode (Garage)	First	High	40	0.76	0.24*	
		Low		0.73	0.21*	
		Idle		0.78	0.52	
	Second	High	26	0.69	0.12*	
		Low		0.42	0.03*	
		Idle		0.62	0.39*	
2500 rpm (Laboratory)	First		40	0.47	0.30*	0.23*
	Second		26	0.37*	0.25*	0.23*
2500 rpm (Garage)	First		40	0.50	0.14*	
	Second		26	0.36*	0.25*	

(a) First Good Data: This data set contains the observations of the first FTP and ST, both of which are valid.

Second Good Data: This data set contains the second pair of FTP and ST observations, both of which are valid.

Average Data: This data set contains the average of the FTP and ST observations on each car (for the Federal Short Cycle and NY/NJ Composite only).

(b) Number of cars in data set

(c) The correlation is statistically significant at the 95% confidence level except when indicated by an asterisk.

1.1.1.1 Hydrocarbon Emission

The bag-type STs (Federal Short Cycle and NY/NJ Composite) and the idle mode of the volumetric or modal tests (Key Mode, Federal Three-Mode) in general show superior HC tracking characteristics. However, on the Federal Three-Mode, the high-speed mode has a slightly higher correlation in some instances than the idle mode. The Unloaded 2500 rpm ST has much poorer HC correlation.

1.1.1.2 Carbon Monoxide Emission

The bag-type STs exhibit the superior CO tracking characteristics, but of a lower correlation level than that achieved for HC. The idle mode of the volumetric tests has higher correlation than the high and low speed modes, but with a rather poor correlation coefficient level. The Unloaded 2500 rpm ST is essentially uncorrelated for CO.

1.1.1.3 Oxides of Nitrogen Emission

The high-speed modes of the volumetric tests display the best ability to track NO_x. The bag-type tests correlate with NO_x, but at a much lower coefficient level. The idle and low-speed volumetric modes and the Unloaded 2500 rpm ST are uncorrelated with NO_x.

1.1.1.4 Modal vs Bag Tests

On the basis of HC and CO correlation, as noted above, the bag tests (Federal Short Cycle and NY/NJ Composite) are preferable to the modal- or volumetric-type ST. The volumetric STs show acute deficiencies in tracking CO. However, the high-speed modes of the volumetric ST have superior NO_x correlation.

An analysis of variance indicated that the percent error due to testing was higher for bag tests than many of the modal tests (using the same laboratory instruments). This higher testing error may be due to variations of vehicle operation while trying to follow the driving profile of the short driving test procedure, rather than due to the bag collection method, per se. The lower testing error of the volumetric tests, on the other hand, may be due to the simplicity of the test procedure itself, in that the measurements are taken at stabilized engine operating conditions.

1.1.1.5 Weighted Modal Tests

A multiple regression analysis was performed for the three-mode volumetric tests on the first good data set. The purpose of this analysis was to empirically determine the linear combinations of like constituents of the three-mode readings that have maximum correlation with the FTP. The results are shown in Table 1-2, along with the maximum correlation using only a single reading on each constituent. As can be seen from the table, the weighted combination correlations are not significantly greater than the correlation of the best single reading.

1.1.1.6 Laboratory Analyzers vs Garage Instruments

The largest differences between the correlation results of the two measurement techniques occur on the second good data sets. However, the sample size of the second good data set, 26 cars, is risky for inference purposes. In general, there is a greater variation in the correlation estimates of first good data and second good data for the garage analyzer than for the laboratory analyzer, as shown in Table 1-1.

The most striking difference between laboratory and garage data is for HC on the Federal Three-Mode. The laboratory measurements for first good data indicate the best mode to be high speed, while the corresponding garage instrument readings indicate the idle mode as superior. This is inconsistent with the results for HC on the Clayton Key Mode where both instrument types indicated the idle mode as superior. Firm inferences are tenuous due to differences in sample size.

CO correlation deficiency is common to both measurement techniques. Due to the low concentration of CO being emitted in the CEV fleet, this may be a measurements problem, in general, rather than a deficiency in ST structure.

Table 1-2. Correlations for Weighted Mode Tests (CEV Fleet)

Short Test	N[a]	Weighted Correlation Coefficient[b]			Best Single-Mode[c] Correlation Coefficient[b]		
		HC	CO	NO_x	HC	CO	NO_x
Key Mode							
Laboratory	40	0.93	0.55	0.83	0.92 (I)	0.54 (I)	0.79 (H)
Garage	40	0.91	0.58		0.88 (I)	0.52 (I)	
Federal Three-Mode							
Laboratory	31	0.91	0.48	0.90	0.87 (H)	0.48 (I)	0.89 (H)
Garage	40	0.81	0.53		0.78 (I)	0.52 (I)	

(a) Number of cars in first good data set; the first pair of FTP and ST observations, both of which are valid

(b) Correlations are statistically significant at the 95% confidence level

(c) H = high speed mode
I = idle mode

1.1.1.7 Sensitivity of Correlation Results

Selected extreme data points were deleted and the correlation coefficient recalculated for the Federal Short Cycle ST to illustrate variability due to the data sample. As shown in Table 1-3, the correlation coefficient is extremely sensitive to a small percentage of the data points.

Table 1-3. Correlations for Selected Car Deletions: Federal Short Cycle vs FTP (CEV Fleet)

Number of Cars Deleted	Correlation Coefficient[a]		
	HC	CO	NO_x
0	0.872	0.810	0.621
1	0.657	0.673	0.690
2	0.656	0.639	0.633
3	--	--	0.823
4	--	--	0.755

(a) Significant at the 95% confidence level

1.1.1.8 ST Correlation Ratings

The following qualitative rating scale was used to rate the ST:

	Rating	Description
(U)	Unacceptable	Constituent is uncorrelated at the 95 percent confidence level
(P)	Poor	Constituent is correlated at the 95 percent confidence level, but with correlation less than 0.6
(F)	Fair	Correlation between 0.6 and 0.7
(G)	Good	Correlation between 0.7 and 0.9
(E)	Excellent	Correlation between 0.9 and 1.0

For rating the three-mode volumetric ST, the mode with the highest rating was used. Table 1-4 shows the ratings of the ST on each pollutant on this basis.

Table 1-4. ST Correlation Ratings (CEV Fleet)

Short Test	Rating		
	HC	CO	NO_x
Federal Short Cycle	G	G	F
NY/NJ Composite	E	G	P
Key Mode			
Laboratory	E (I)[(a)]	P (I)	G (H)
Garage	G (I)	P (I)	
Federal Three-Mode			
Laboratory	G (H)	P (I)	G (H)
Garage	G (I)	P (I)	
2500 rpm Unloaded			
Laboratory	P	U	U
Garage	P	U	

(a) I = idle mode, H = high speed mode

In general, the STs have less difficulty tracking HC than CO and NO_x. Excluding the Unloaded 2500 rpm ST (which has either "P" or "U" ratings for all three pollutants), the bag-type and modal STs all have "G" to "E" ratings for HC. In the case of CO, the bag-type STs have "G" ratings, whereas the modal STs are rated in the "P" category. This situation is reversed in the case of NO_x, where the modal STs have "G" ratings and the bag-type STs are rated "F" to "P". Hence, the choices among the STs for CO and NO_x implementation may be more limited than for HC.

1.1.2 Contingency Table Analysis Results

The contingency table analysis technique was used to establish the ST pass-fail levels for each pollutant. The contingency table is defined in Table 1-5, along with its associated parameters. A pictorial demonstration of its application to a given data set is shown in Figure 1-1. It can be seen that, for a given data set, part of the analysis is concerned with the criteria used to select the ST cut-points. In this regard, the bounded errors of commission method was used extensively to establish trends for the variations in E_c, E_o, FF, and PP. In this method, the ST cut-points are selected to minimize E_o while holding the E_c below a specified level. It thus permits a direct

Table 1-5. Contingency Table

		True = FTP		
		Pass	Fail	Total
Predicted = Short Test	Pass	a	b	a + b
	Fail	c	d	c + d
	Total	a + c	b + d	n = a + b + c + d

a = number of correctly passed vehicles (PP)

b = number of errors of omission (E_o)

c = number of errors of commission (E_c)

d = number of correctly failed vehicles (FF)

Sensitivity = a/(a + c)
Specificity = b/(b + d)
False positive error = b/(a + b)
False negative error = c/(c + d)

$$\text{Correlation index} = \frac{ad - bc}{[(a + b)(a + c)(b + d)(c + d)]^{1/2}}$$

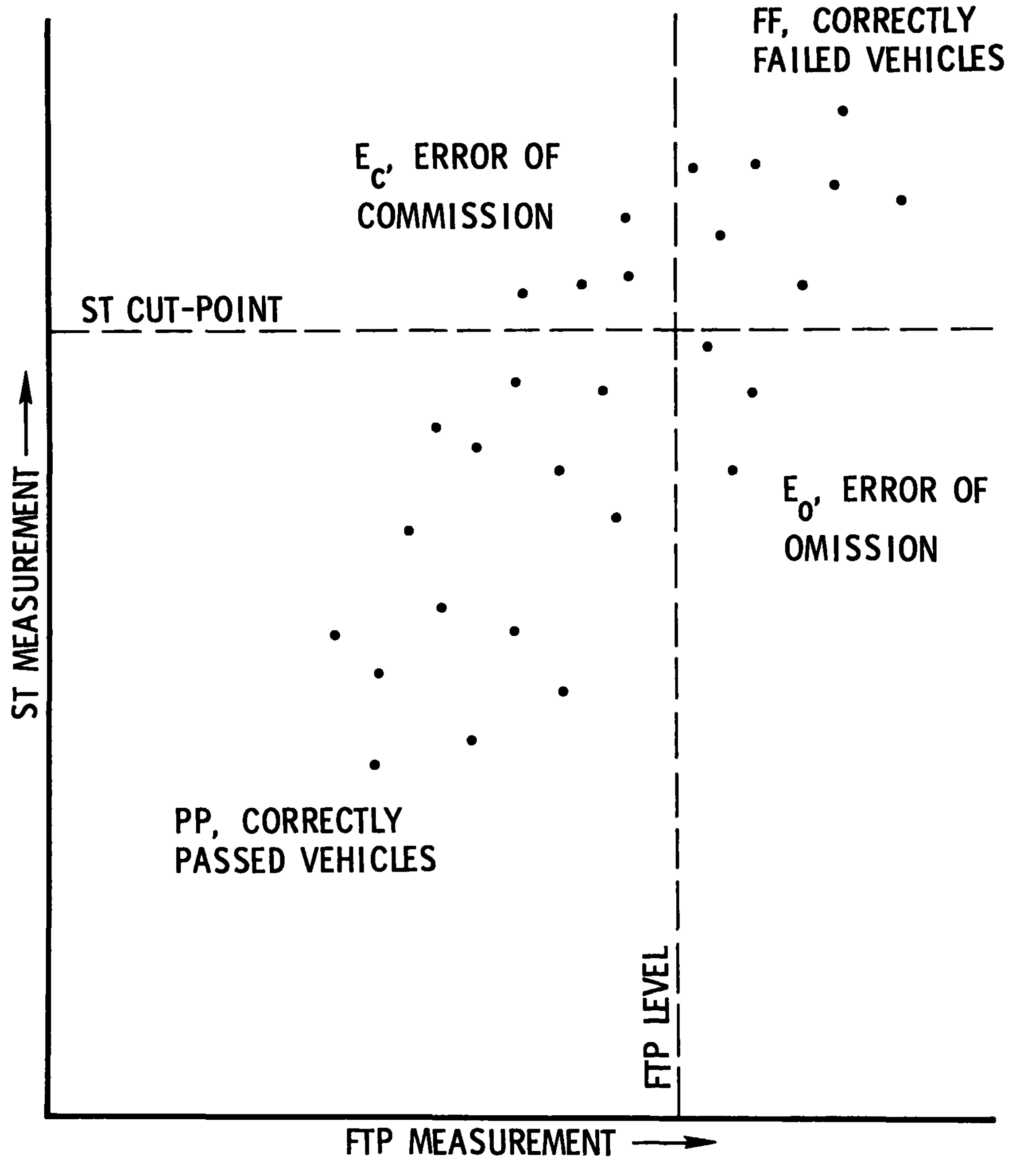


Figure 1-1. Contingency Table Representation

answer to the question, "For a given permissible level of E_c, what level of E_o is associated with the ST, and with what impact on air quality (inferred from number of FF and E_o vehicles)?" This method is illustrated in Figure 1-2. The policy decision is the maximum allowable E_c.

With regard to procedural technique, a bivariate normal distribution model was fitted to a particular data set by incorporating the correlation coefficient, mean values, and standard deviations of the data set. The ST cut-points were then determined by using the model for the predicted population of the CEV fleet.

As the appropriate FTP standards to which the CEV fleet was designed were uncertain, four sets of FTP cut-points were used in the analysis, as specified in Table 1-6. The bound of the errors of commission was varied from 5 percent to 1 percent in 1-percent increments, with the values 0.5 percent and 0.1 percent also included.

1.1.2.1 Hydrocarbon Emission

The variation of E_c, E_o, and FF as a function of HC cut-point was graphically determined for each ST examined. The results for the Federal Short Cycle are shown in Figure 1-3 to indicate the general nature of the

Table 1-6. Assumed FTP Levels for CEV Fleet

Level	Emission Levels, gm/mi		
	HC	CO	NO_x
I	0.41	3.4	3.1
II	0.60	5.0	3.1
III	0.75	7.0	3.1
IV	0.90	9.0	3.1

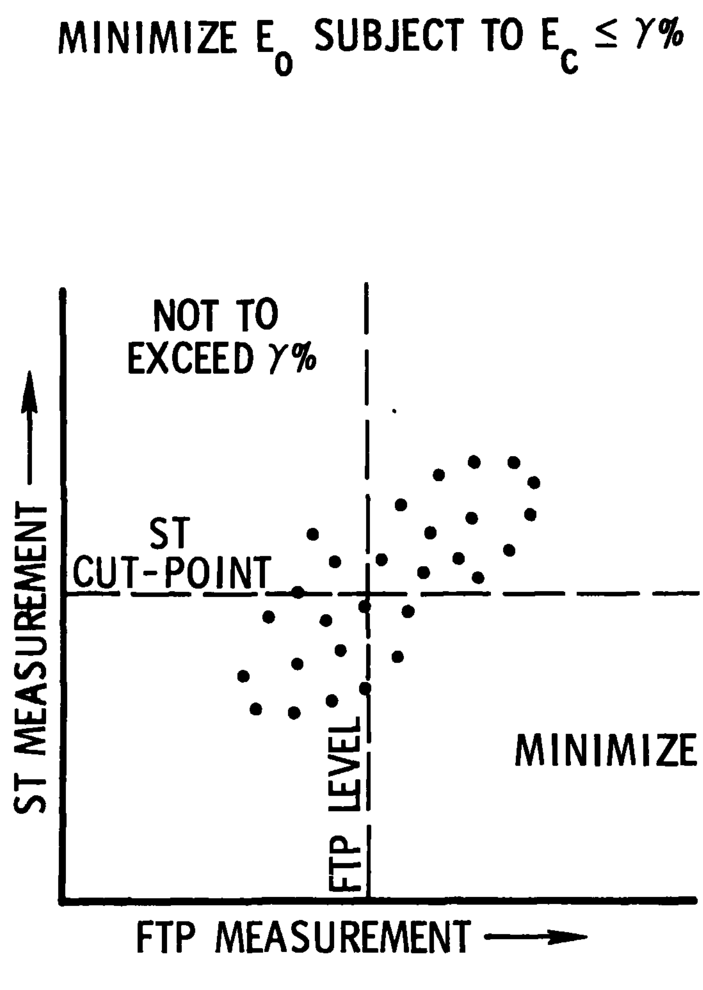


Figure 1-2. Bounded Errors of Commission Method

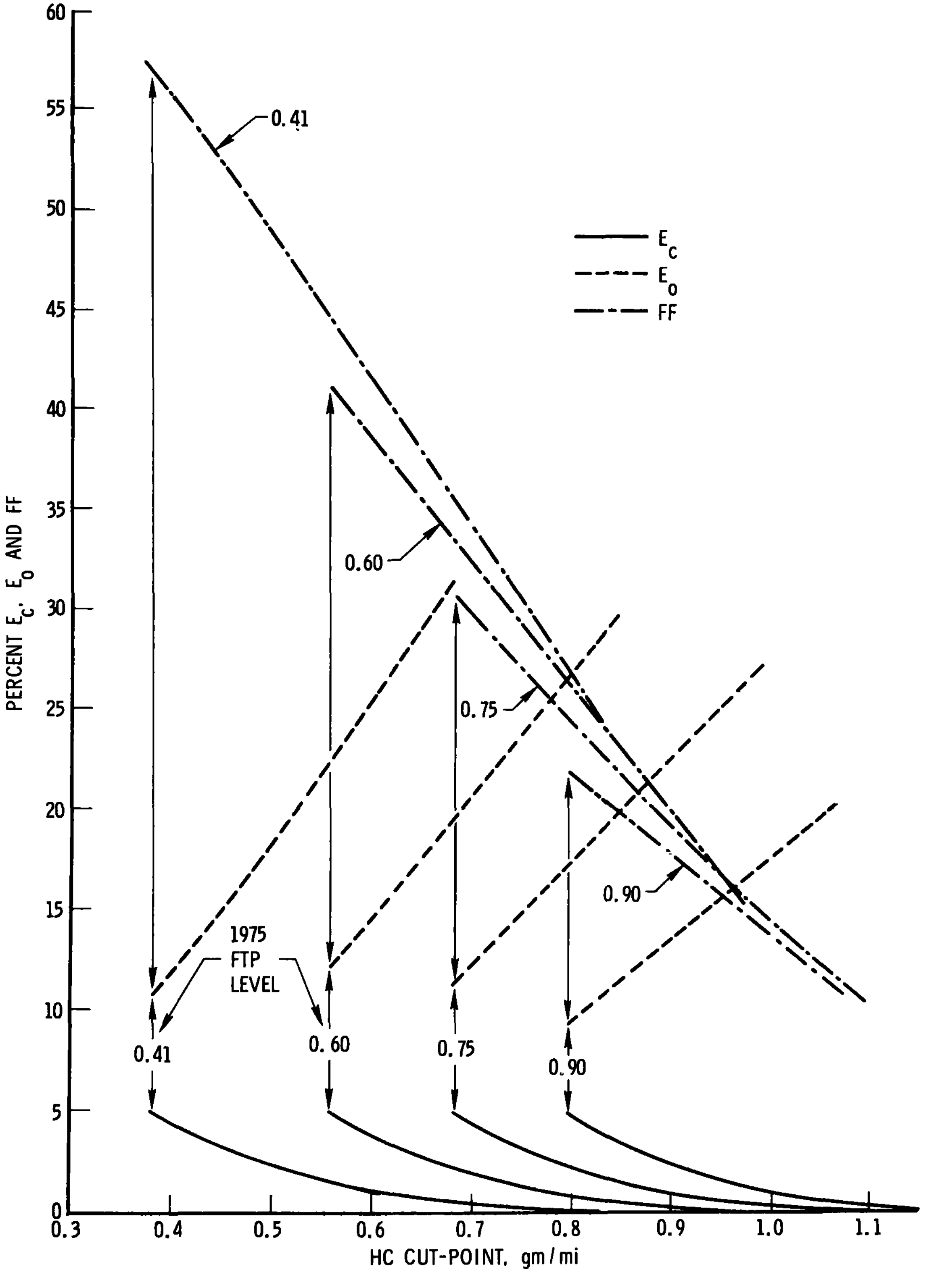


Figure 1-3. Variation of E_C, E_O, and FF with HC Cut-Point; CEV Fleet; Federal Short Cycle; Bounded Errors of Commission Method

tradeoffs available for policy formulation. Reducing the E_c increases E_o and decreases FF. All STs had similar trends. To illustrate specific values and trends among the STs, Tables 1-7 and 1-8 summarize data from the graphical displays at HC FTP levels of 0.41 and 0.90. On the average, at both FTP levels, the bag tests (Federal Short Cycle and NY/NJ Composite) have lower E_o and higher FF at the fixed E_c = 5 percent than do the volumetric tests. However, the idle mode of the Clayton Key Mode (with either laboratory or garage instruments) test produces similar results. The Unloaded 2500 rpm test is very poor on a comparative basis.

1.1.2.2 Carbon Monoxide Emission

The variation of E_c, E_o, and FF as a function of CO cut-point was also graphically determined for each ST examined, and for the range of CO FTP values selected in Table 1-6 (CO = 3.4 to 9). Figure 1-4 indicates results for the Federal Short Cycle. As in the preceding case of hydrocarbon emissions, these displays indicated the tradeoffs possible between E_c, E_o, and FF. However, for CO FTP levels above 3.4, the general or average CO levels of the CEV fleet were sufficiently low; i.e., a very high percentage of the vehicles exceeded the 5-, 7-. and 9-gm/mi requirements, so that both E_o and FF percentage values were very small for all of the short test procedures. This characteristic is summarized in Table 1-9 for the CO FTP level of 9 gm/mi; the E_o and FF values are less than 1 percent for all the STs.

At the 3.4 level, however, as shown in Table 1-10, the bag tests were sufficiently discriminatory to identify FF values above 20 percent, with E_o values in the 14- to 16-percent range. The volumetric tests, on the other hand, all had high E_o values (30- to 40-percent range), with very low FF values (<16).

1.1.2.3 Oxides of Nitrogen Emission

The variations of E_c, E_o, and FF as a function of NO_x cut-point were also graphically determined for each ST examined, for the single NO_x FTP value of 3.1 gm/mi examined in the study. Figure 1-5 illustrates results for the Federal Short Cycle.

Table 1-7. Comparison of Selected ST Hydrocarbon Results: CEV Fleet, Bounded Errors of Commission Analysis, HC FTP Level = 0.41 gm/mile (E_c = constant = 5%)

Short Test	Parameter, %	
	E_o	FF
Federal Short Cycle	11	56
NY/NJ Composite	7	60
Clayton Key Mode (Laboratory)		
Idle	7	61
Low Speed	35	32
High Speed	30	37
Clayton Key Mode (Garage)		
Idle	10	57
High Speed	21	45
Federal Three-Mode (Laboratory)		
Idle	17	52
Low Speed	17	38
High Speed	11	51
Federal Three-Mode (Garage)		
Idle	18	46
Low Speed	22	44
High Speed	20	47
2500 rpm Unloaded (Laboratory)	38	28
2500 rpm Unloaded (Garage)	37	30

Table 1-8. Comparison of Selected ST Hydrocarbon Results: CEV Fleet, Bounded Errors of Commission Analysis, HC FTP Level = 0.90 gm/mile (E_c = constant = 5%)

Short Test	Parameter, %	
	E_o	FF
Federal Short Cycle	9	22
NY/NJ Composite	6.5	25
Clayton Key Mode (Laboratory)		
Idle	6	22
Low Speed	21	9
High Speed	19.5	10
Clayton Key Mode (Garage)		
Idle	9.5	22
High Speed	16	16
Federal Three-Mode (Laboratory)		
Idle	15	21
Low Speed	15	21
High Speed	10	25
Federal Three-Mode (Garage)		
Idle	14	17
Low Speed	16	16
High Speed	15	17
2500 rpm Unloaded (Laboratory)	23	8
2500 rpm Unloaded (Garage)	23	9

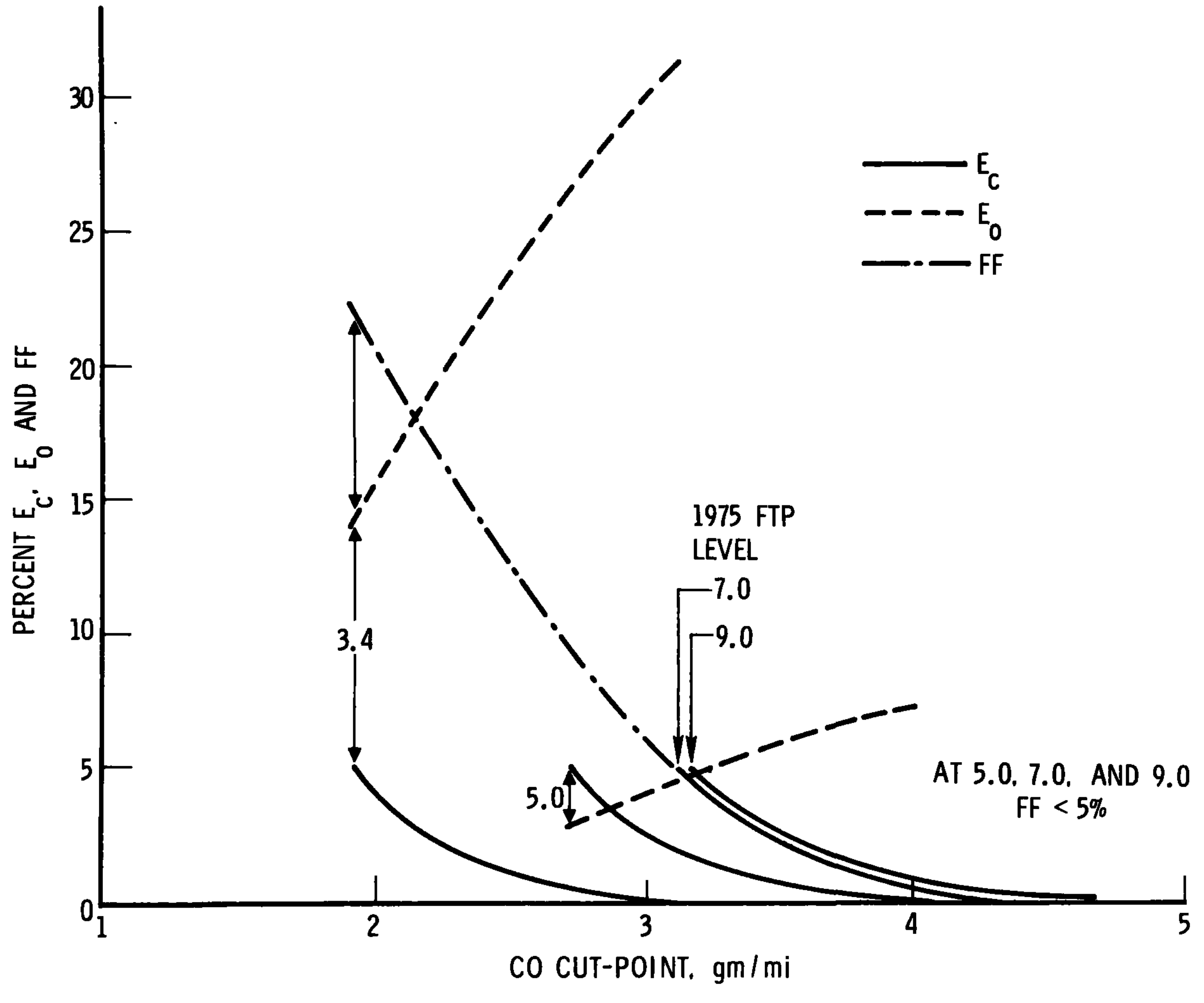


Figure 1-4. Variation of E_c, E_o, and FF with CO Cut-Point; CEV Fleet; Federal Short Cycle; Bounded Errors of Commission Method

Table 1-9. Comparison of Selected ST Carbon Monoxide Results: CEV Fleet, Bounded Errors of Commission Analysis, CO FTP Level = 9.0 gm/mi (E_c = constant = 5%)

Short Test	Parameter, %	
	E_o	FF
Federal Short Cycle	< 1	< 1
NY/NJ Composite	< 1	< 1
Clayton Key Mode (Laboratory)		
Idle	< 1	< 1
Low Speed	< 1	< 1
High Speed	< 1	< 1
Clayton Key Mode (Garage)		
Idle	< 1	< 1
Low Speed	< 1	< 1
High Speed	< 1	< 1
Federal Three-Mode (Laboratory)		
Idle	< 1	< 1
Low Speed	< 1	< 1
High Speed	< 1	< 1
Federal Three-Mode (Garage)		
Idle	< 1	< 1
Low Speed	< 1	< 1
High Speed	< 1	< 1
2500 rpm Unloaded (Laboratory)	< 1	< 1
2500 rpm Unloaded (Garage)	< 1	< 1

Table 1-10. Comparison of Selected ST Carbon Monoxide Results: CEV Fleet, Bounded Errors of Commission Analysis, CO FTP Level = 3.4 gm/mi (E_c = constant = 5%)

Short Test	Parameter, %	
	E_o	FF
Federal Short Cycle	14	22
NY/NJ Composite	16	20
Clayton Key Mode (Laboratory)		
Idle	29	15
Low Speed	33	11
High Speed	36	8
Clayton Key Mode (Garage)		
Idle	29	14
Low Speed	36	7
High Speed	33	10
Federal Three-Mode (Laboratory)		
Idle	33	16
Low Speed	40	8
High Speed	43	7
Federal Three-Mode (Garage)		
Idle	29	14
Low Speed	36	7
High Speed	36	7.5
2500 rpm Unloaded (Laboratory)	35	8
2500 rpm Unloaded (Garage)	38	6

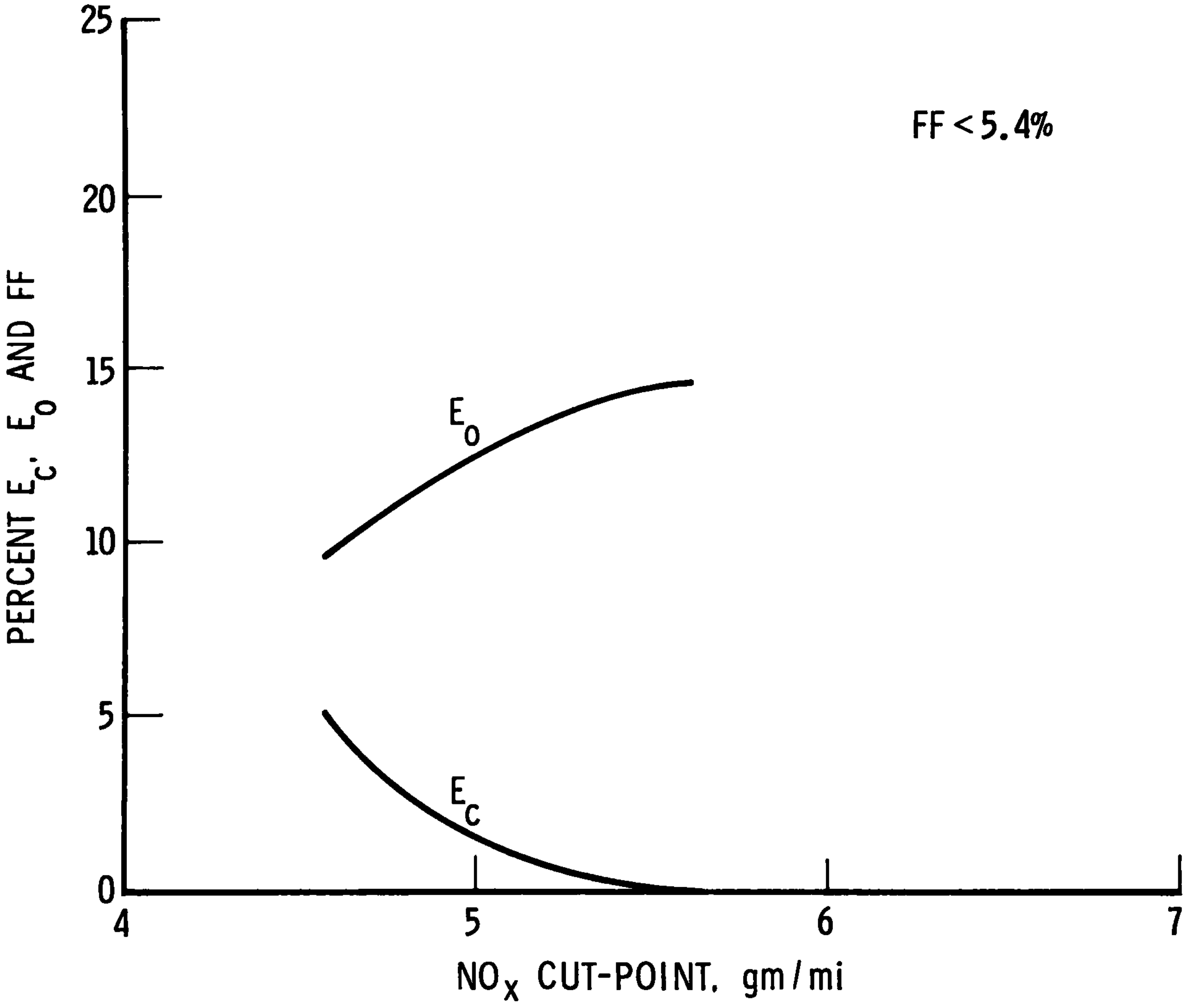


Figure 1-5. Variation of E_C, E_O, and FF with NO_x Cut-Point; CEV Fleet; Federal Short Cycle; Bounded Errors of Commission Method

The significant results at the E_c level of 5 percent are summarized in Table 1-11 for comparative purposes. As can be noted, the high-speed mode of the volumetric tests (Clayton Key Mode and Federal Three-Mode) produced the highest FF values and the lowest E_o values, and are thus indicated to be superior for NO_x discrimination purposes.

1.1.2.4 Weighted Three-Mode Tests

Contingency table analyses were also made for two different-weighted Key Mode tests. The results indicated that the weighted volumetric tests are not significantly better than the best single mode, as was also concluded from conventional correlation analyses (see Sec. 1.1.1.5).

1.1.2.5 Variance Effects

Since the variations in E_c, E_o, and FF with ST cut-point noted previously are predictions from the data, the variability of the predictions was analyzed. The uncertainty in the predicted results increases when decreasing the bounds of the errors of commission, as illustrated in Figure 1-6 for HC on the Federal Short Cycle.

1.1.2.6 Laboratory vs Garage Instruments

Tables 1-7 through 1-10 indicate that generally similar levels of E_o and FF were obtained with both laboratory and garage analyzers for the HC and CO ranges examined for the CEV fleet.

1.1.2.7 Modal vs Bag Tests

In terms of HC and CO discrimination, as noted above, the bag tests are superior to the modal ST. The modal STs all have high E_o and low FF values. In terms of NO_x discrimination, the high-speed mode of the volumetric ST was superior. These results agree with those predicted from conventional correlation analysis in Sec. 1.1.1.4.

1.1.2.8 Multiple-Constituent Tests

In addition to analyzing each pollutant individually, an analysis was made for three-constituent tests. In a three-constituent test, a car fails

Table 1-11. Comparison of Selected ST NO_x Results: CEV Fleet, Bounded Errors of Commission Analysis, NO_x FTP Level = 3.1 gm/mi (E_c = constant = 5%)

Short Test	Parameter, %	
	E_o	FF
Federal Short Cycle	9.5	5.5
NY/NJ Composite	10	5
Clayton Key Mode (Laboratory)[a]		
Idle	13	2
Low Speed	14	<2
High Speed	6.5	8.5
Federal Three-Mode (Laboratory)[a]		
Idle	11	1
Low Speed	11	1
High Speed	3	8.5
2500 rpm Unloaded (Laboratory)[a]	13	2

(a) Garage-type analyzers for NO_x were not available for ST evaluation.

the ST if any of its HC, CO, and NO_x measurements exceed the previously determined cut-points. These tests are applicable to the bag tests, the unloaded test, and the individual modes of the three-mode volumetric tests.

The three-constituent test results for the Federal Short Cycle and the Federal Three-Mode (high speed and idle modes only) were computed and graphically summarized as a function of predicted E_c. Table 1-12 summarizes these results for the predicted E_c value of 5 percent. Both the laboratory and garage instrument results are displayed for the Federal Three-Mode short test.

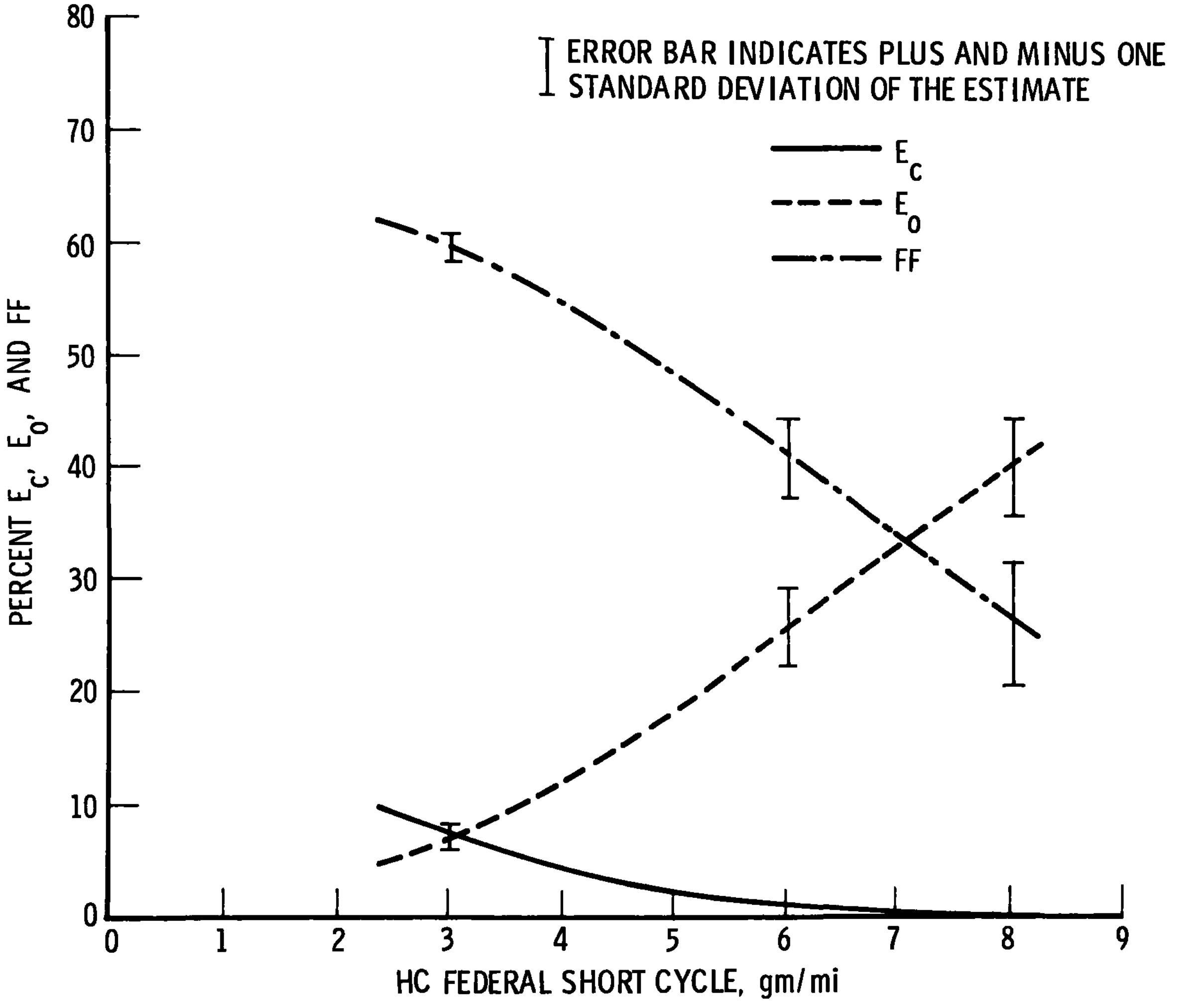


Figure 1-6. Variability of Predicted Population Results

Table 1-12. Comparison of Three-Constituent Test Results: CEV Fleet, Bounded Errors of Commission Analysis, (Predicted E_c = constant = 5%)

Short Test	FTP Level	Parameter, %		
		Actual E_c	Actual E_o	Actual FF
Federal Short Cycle	1	5	16	48
	2	8	16	25
	3	7.5	8	20
	4	7.5	6	17
Federal Three-Mode (Laboratory)				
Idle	1	0	36	36
	2	3	28	17
	3	3	16	16
	4	13	16	7
High Speed	1	3.5	16	54
	2	9.5	13	35
	3	9.5	10	23
	4	13	7	16
Federal Three-Mode (Garage)				
Idle	1	10	36	30
	2	2.5	25	18
	3	0	14	16
	4	5	13.5	11.5
High Speed	1	10	30	36
	2	15	18	25
	3	10	6	24.5
	4	5	6.5	18

With laboratory instrument measurements, as the FTP cut-points increase from level Set I to level Set IV. the resulting actual errors of commission tend to increase for the given predicted level of errors of commission. This trend is <u>not</u> present for the garage instrument results shown.

A comparison of the modes on the Federal Three-Mode test shows that, for the fixed predicted percent E_c, the high speed mode has a higher percent FF and lower percent E_o than does the idle mode. This is true regardless of instrumentation or FTP level. However, the actual percent E_c is generally lower on the idle mode than on the high-speed mode, but this difference is not always significant.

A comparison of different modes or ST should be made on a fixed actual percent E_c basis. This is, of course, difficult to do because of the computational procedure followed. It can be approximately performed, however. Consider comparing the Federal Short Cycle to the Federal Three-Mode. At FTP level I, the actual percent E_c is <u>approximately</u> the same for the high-speed mode and the Federal Short Cycle (statistically, they are the same). Now, comparing the percent FF and percent E_o values, percent FF and percent E_o are both higher on the high-speed mode than the Federal Short Cycle. This difference is not statistically significant at the 95 percent confidence level, and the two tests would have to be judged as equal. Also, at the 95 percent confidence level, the high-speed mode is superior to the idle mode.

The differences between laboratory and garage instruments are quite predictable, based upon the previous results from individual pollutants. For the fixed predicted percent E_c, on their respective modes,

a. Actual percent E_c is higher for garage instruments than for laboratory instruments

b. Actual percent FF is lower for garage instruments than for laboratory instruments

c. Actual percent E_o is higher for garage instruments than for laboratory instruments.

1.2 IN-USE 1974 MODEL YEAR VEHICLE FLEET

1.2.1 Direct Relatability Results

A conventional correlation analysis was made for the 1974 model year fleet to assess direct relatability between the five short tests and the FTP. The method was the same as described for the CEV fleet in Sec. 1.1.1. The resulting ST/FTP correlation coefficients for HC, CO, and NO_x are summarized in Table 1-13 for the three individual inertia test weight groups (A = 4000 lb, B = 2750 lb, and C = 5500 lb) and for the pooled vehicle population (combined groups A, B, and C).

1.2.1.1 Hydrocarbon Emission

For the pooled fleet, the bag-type STs (Federal Short Cycle and NY/NJ Composite), the idle mode of the modal STs with laboratory analyzers, and the Unloaded 2500 rpm ST with laboratory analyzers in general exhibit the better HC tracking characteristics.

For Group A, similar results apply.

For Group B, the results are similar to the pooled fleet except that in some instances the low-speed mode of the Key Mode and the low and high-speed modes of the Federal Three-Mode test have a slightly higher correlation coefficient than the idle mode.

For Group C, none of the STs are able to track HC with any reasonably high degree of correlation.

1.2.1.2 Carbon Monoxide Emission

For the pooled fleet, the bag-type STs, the idle and low-speed modes of the modal tests with laboratory analyzers, and the Unloaded 2500 rpm ST with laboratory analyzers in general exhibit the better CO tracking characteristics.

For Groups A and B, similar results apply except that the low-speed mode is superior to the idle mode in the modal tests.

Table 1-13. Correlation Coefficient Summary: 1974 Model Year Fleet

Short Test	Vehicle Group[a]	Test Mode	N[b]	ST/FTP Correlation Coefficient[c]		
				HC	CO	NO_x
Federal Short Cycle	Pooled		147	0.932	0.905	0.355
	A		50	0.933	0.972	0.780
	B		48	0.897	0.897	0.104*
	C		49	0.383	0.476	0.674
NY/NJ Composite	Pooled		147	0.906	0.890	0.060*
	A		50	0.911	0.950	0.733
	B		48	0.920	0.857	0.005*
	C		49	0.513	0.498	0.611
Key Mode (Laboratory)	Pooled	High	147	0.757	0.518	0.521
		Low		0.776	0.769	0.419
		Idle		0.793	0.739	0.463
	A	High	50	0.590	0.514	0.562
		Low		0.595	0.827	0.495
		Idle		0.723	0.704	0.381
	B	High	48	0.812	0.262*	0.731
		Low		0.868	0.738	0.635
		Idle		0.825	0.650	0.548
	C	High	49	0.238*	-0.195*	0.555
		Low		0.228*	0.435	0.580
		Idle		0.460	0.757	0.571
Key Mode (Garage)	Pooled	High	145	0.528	0.507	
		Low		0.545	0.472	
		Idle		0.455	0.470	
	A	High	50	0.228*	0.563	
		Low		0.151*	0.652	
		Idle		0.245*	0.372	

Table 1-13. Correlation Coefficient Summary: 1974 Model Year Fleet (Continued)

Short Test	Vehicle Group(a)	Test Mode	N(b)	ST/FTP Correlation Coefficient(c)		
				HC	CO	NO_x
	B	High	46	0.478	0.362	
		Low		0.765	0.540	
		Idle		0.692	0.560	
	C	High	49	0.191*	-0.221*	
		Low		0.198*	-0.091*	
		Idle		0.100*	0.229*	
Federal Three-Mode (Laboratory)	Pooled	High	147	0.766	0.604	0.467
		Low		0.771	0.729	0.453
		Idle		0.803	0.734	0.411
	A	High	50	0.507	0.717	0.492
		Low		0.523	0.801	0.664
		Idle		0.709	0.724	0.369
	B	High	48	0.890	0.278*	0.722
		Low		0.859	0.737	0.611
		Idle		0.851	0.622	0.665
	C	High	49	0.522	0.159*	0.552
		Low		0.533	0.592	0.707
		Idle		0.252*	0.733	0.639
Federal Three-Mode (Garage)	Pooled	High	145	0.474	0.387	
		Low		0.531	0.409	
		Idle		0.632	0.476	
	A	High	50	0.138*	0.533	
		Low		0.107*	0.597	
		Idle		0.660	0.397	

Table 1-13. Correlation Coefficient Summary: 1974 Model Year Fleet (Continued)

Short Test	Vehicle Group[a]	Test Mode	N[b]	ST/FTP Correlation Coefficient[c]		
				HC	CO	NO_x
	B	High	46	0.536	0.268*	
		Low		0.763	0.539	
		Idle		0.717	0.550	
	C	High	49	0.095*	-0.083*	
		Low		-0.008*	0.239*	
		Idle		-0.060*	0.392	
2500 rpm Unloaded (Laboratory)	Pooled		147	0.809	0.740	0.447
	A		50	0.832	0.812	0.524
	B		48	0.865	0.724	0.577
	C		49	0.107*	0.350	0.679
2500 rpm Unloaded (Garage)	Pooled		147	0.574	0.447	
	A		50	0.487	0.676	
	B		46	0.781	0.684	
	C		49	-0.064*	-0.051*	

(a) A = Chrysler (4000 lb)
B = Ford (2750 lb)
C = Chevrolet (5500 lb)
Pooled = Groups A + B + C

(b) Number of cars in the data set

(c) The correlations are statistically significant at the 95 percent confidence level except where indicated by an asterisk. ST and FTP uncorrelated for correlations below 0.28.

For Group C, the idle mode of the Key Mode and Federal Three-Mode (with laboratory analyzers) are superior, although the low-speed modes of these STs and the bag-type tests are correlated with CO at lower correlation coefficient levels. The other STs are essentially uncorrelated with CO for Group C.

1.2.1.3 Oxides of Nitrogen Emission

For the pooled fleet, all modes of the Key Mode and Federal Three-Mode and the Unloaded 2500 rpm ST have similar correlations in the 0.41 and 0.52 range; the Federal Short Cycle correlates at a lower value (0.36), while the NY/NJ Composite bag test is uncorrelated.

For Group A, however, the bag-type STs have the highest correlation coefficients observed for NO_x (0.73 to 0.78), while the modal and Unloaded 2500 rpm ST results are similar to those of the pooled fleet.

For Group B, the results are similar to those for the pooled fleet except that the bag-type STs are not correlated at all for NO_x. Here the range of correlation coefficients for the modal and Unloaded 2500 rpm STs is from 0.55 to 0.73, with the highest values obtained in the high-speed mode.

The Group C results are similar to those for Group A.

There is no single ST with good NO_x correlation across the 1974 model year fleet population.

1.2.1.4 Modal vs Bag Tests

In terms of HC and CO emissions correlation, the bag-type STs are superior for Groups A, B, and the pooled population. For Group C the idle mode of the Key Mode and Federal Three-Mode STs has the higher correlation for CO; the idle mode of the Key Mode and the low- and high-speed modes of the Federal Three-Mode are essentially the same as the bag-type STs in terms of HC discrimination capability.

In terms of NO_x correlation, the bag-type and modal STs are essentially equivalent for Group C, whereas the bag-type STs are clearly superior for Group A. The modal tests are superior for Group B and the pooled fleet.

1.2.1.5 Laboratory Analyzers vs Garage Instruments

From an HC and CO correlation viewpoint, the garage analyzers are inferior to the laboratory analyzers in that they have lower correlation coefficients than the laboratory analyzers for HC and CO in each corresponding test mode. They do, however, tend to identify the same superior test modes as the laboratory analyzers, and can have reasonably high correlation coefficients, although there is a wide variation for the three groups examined in the 1974 model year fleet.

To illustrate, consider the idle mode of the Federal Three-Mode ST, which for the pooled fleet resulted in representatively high correlation coefficients for HC and CO with laboratory analyzers: 0.80 and 0.73, respectively. With garage instruments, these correlation coefficients dropped to 0.63 and 0.48, respectively.

In the case of Group A, the laboratory analyzer HC and CO values were 0.71 and 0.72, whereas the garage instrument values were reduced to 0.66 and 0.40.

Group B HC and CO values for laboratory analyzers were 0.85 and 0.62. With garage instruments, they were lowered to 0.72 and 0.55.

In the case of Group C, the HC correlation coefficient of 0.25 with laboratory instruments was not statistically significant at the 95 percent confidence level, while the CO correlation coefficient was 0.73. With garage instruments, these values dropped to -0.06 and 0.39, respectively. In addition, all other ST test modes with garage instruments were uncorrelated for HC and CO for Group C. This was the only group exhibiting these characteristics, although it also had generally poorer HC and CO correlation coefficients than the other groups when laboratory analyzers were used.

This group-peculiar characteristic raises the issue as to whether it is related to inertia test weight factors or to vehicle manufacturer, since each inertia test weight group was made by a different automotive company. There are insufficient data to evaluate this issue at this time; however, a comparison can be made between the 2750-lb Pintos of Group B above and the 5000-lb Galaxies of the CEV fleet in Section 1.1, since both were manufactured by the Ford Motor Company.

Again, using the idle mode of the Federal Three-Mode ST for comparison purposes, the use of garage instruments instead of laboratory instruments for the CEV Galaxies reduced the HC correlation coefficient from 0.80 to 0.78, and increased the CO correlation coefficient from 0.48 to 0.52 (see Table 1-1). These ranges are similar to those reported above for Group B (Pintos), even though the Galaxies were catalyst-equipped and the Pintos were not.

Thus, it appears that additional examinations may be required of possible manufacturer-related effects (e.g., idle fuel-air ratio tolerance bands and quality control measures) in order to fully understand their impact upon measurement instrument type for short test purposes.

1.2.1.6 ST Ratings

ST ratings, using the scale established for the CEV fleet in Sec. 1.1.1.8, are given in Table 1-14. As can be seen, no single ST performs consistently well on all three individual groups, or on a pooled basis. Generally, the STs are unable to track HC and CO emission levels on Group C.

As with the CEV fleet, the bag-type STs have higher ratings than the volumetric tests. The Unloaded 2500 rpm ST shows substantially higher correlation for the 1974 model year fleet than for the CEV fleet (as shown in Table 1-4). The extreme CO tracking deficiency for the CEV fleet data is not evident for the 1974 model year fleet.

1.2.2 Contingency Table Analysis Results

A contingency table analysis, using the bounded errors of commission method described in Sec. 1.1.2 for the CEV fleet, was also performed for the 1974 model year fleet, with the results as discussed below.

Table 1-14. ST Ratings: 1974 Model Year Fleet

Short Test	Vehicle Group[a]	Ratings[b]		
		HC	CO	NO_x
Federal Short Cycle	Pooled	E	E	P
	A	E	E	G
	B	G	E	U
	C	P	P	F
NY/NJ Composite	Pooled	E	G	U
	A	E	E	G
	B	E	G	U
	C	P	P	F
Key Mode (Laboratory)	Pooled	G (I)[c]	G (L)	P (H)
	A	G (I)	G (L)	P (H)
	B	G (L)	G (L)	G (H)
	C	P (I)	G (I)	P (L)
Key Mode (Garage)	Pooled	P (L)	P (H)	
	A	U	F (L)	
	B	G (L)	P (L)	
	C	U	U	
Federal Three-Mode (Laboratory)	Pooled	G (I)	G (I)	P (H)
	A	G (I)	G (L)	F (L)
	B	G (H)	G (I)	G (H)
	C	P (L)	G (I)	G (L)
Federal Three-Mode (Garage)	Pooled	F (I)	P (I)	
	A	F (I)	P (L)	
	B	G (L)	P (I)	
	C	U	P (I)	

Table 1-14. ST Ratings: 1974 Model Year Fleet (Continued)

Short Test	Vehicle Group[a]	Ratings[b]		
		HC	CO	NO_x
2500 rpm Unloaded (Laboratory)	Pooled	G	G	P
	A	G	G	P
	B	G	G	P
	C	U	P	F
2500 rpm Unloaded (Garage)	Pooled	P	P	
	A	P	F	
	B	G	F	
	C	U	U	

[a] A = Chrysler (4000 lb)
B = Ford (2750 lb)
C = Chevrolet (5500 lb)
Pooled = Groups A + B + C

[b] Rating scale as in Sec. 1.1.1.8

[c] I = idle
L = low speed mode
H = high speed mode

1.2.2.1 Hydrocarbon Emission

The variation of E_c, E_o, and FF as a function of HC cut-point was graphically determined for each ST. The results for the Federal Short Cycle are shown in Figure 1-7 to indicate the general trends. All STs had similar trends. To illustrate specific values and trends among the STs, Table 1-15 summarizes data for the E_c value of 5 percent.

The bag tests (Federal Short Cycle and NY/NJ Composite) have lower E_o and higher FF at the fixed E_c = 5 percent condition than do the volumetric tests. There is little difference shown between the various volumetric STs.

1.2.2.2 Carbon Monoxide Emission

The variations of E_c, E_o, and FF as a function of CO cut-point were also graphically determined. Figure 1-8 indicates results for the Federal Short Cycle.

To illustrate specific values and trends among the STs, Table 1-16 summarizes data from the figures for the E_c value of 5 percent.

The bag-type STs (Federal Short Cycle and NY/NJ Composite) exhibit excellent CO tracking characteristics; the E_o values are considerably better (lower) than the volumetric tests, and the FF values are the highest. When garage-type instruments are used, the E_o values are essentially doubled (over laboratory instrument values) and FF values are significantly reduced.

1.2.2.3 Oxides of Nitrogen Emission

Figure 1-7 also indicates the variation of E_c, E_o, and FF as a function of NO_x cut-point for the Federal Short Cycle.

The significant results for each ST at the E_c level of 5 percent are summarized in Table 1-17 for comparative purposes. As can be noted, all STs identified very low percentages of correctly failed vehicles (FF), less than 5 percent, while having significant errors of omission, approximately 15 percent.

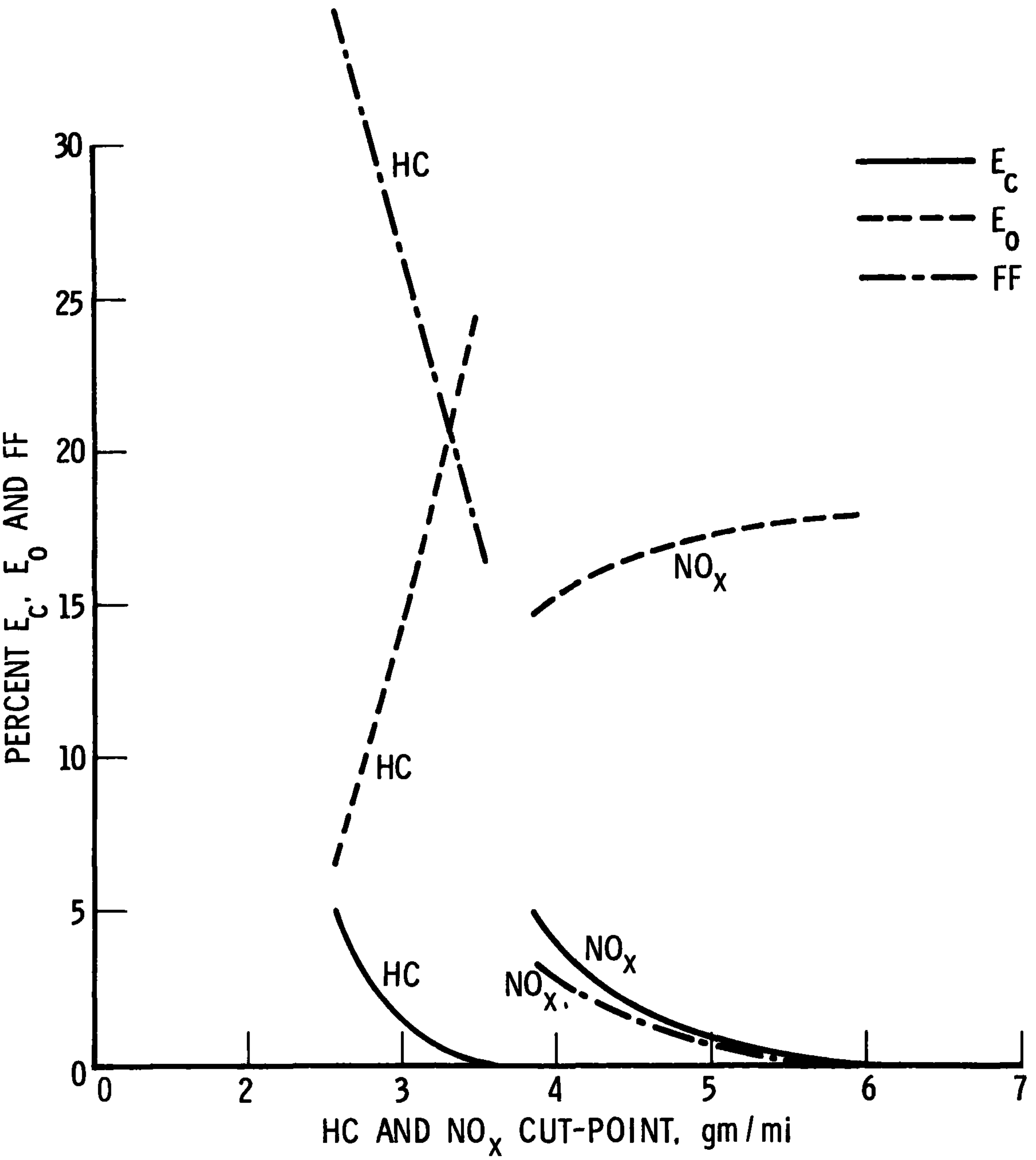


Figure 1-7. Variation of E_C, E_O, and FF with HC and NO_X Cut-Points; 1974 Model Year Fleet; Federal Short Cycle; Bounded Errors of Commission Method

Table 1-15. Comparison of ST Hydrocarbon Results: 1974 Model Year Fleet, Bounded Errors of Commission Analysis (E_c = constant = 5%)

Short Test	Parameter, %	
	E_o	FF
Federal Short Cycle	6.5	34.5
NY/NJ Composite	8.5	32
Clayton Key Mode (Laboratory)		
Idle	16	24.5
Low Speed	17	23.6
High Speed	18	22.5
Clayton Key Mode (Garage)		
Idle	11.5	29
Low Speed	14	27
High Speed	13	28
Federal Three-Mode (Laboratory)		
Idle	15.5	25
Low Speed	17.5	23
High Speed	18	23
Federal Three-Mode (Garage)		
Idle	17	24
Low Speed	14	27
High Speed	12	29
2500 rpm Unloaded (Laboratory)	16	26
2500 rpm Unloaded (Garage)	16	26

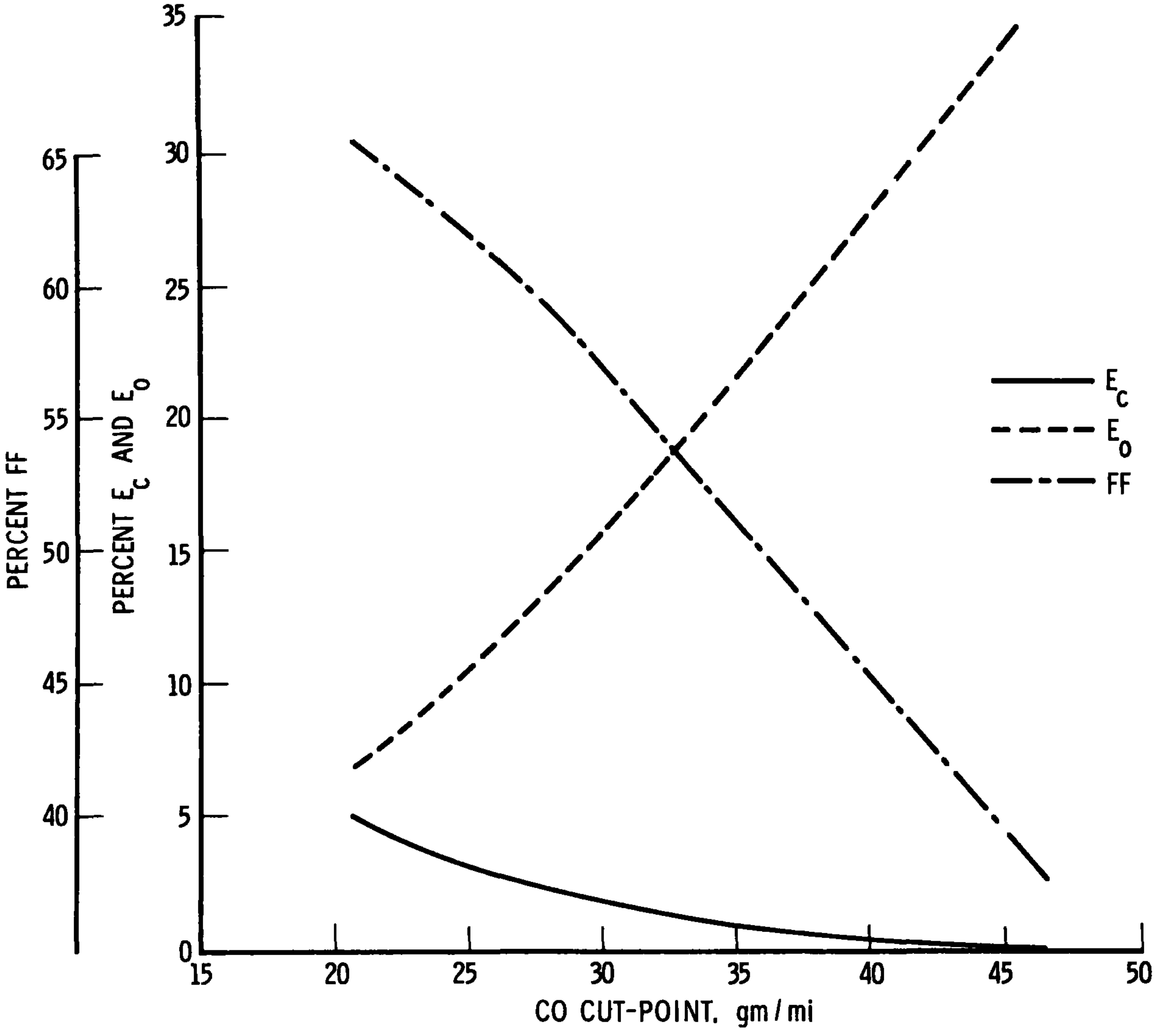


Figure 1-8. Variation of E_C, E_O, and FF with CO Cut-Point; 1974 Model Year Fleet; Federal Short Cycle; Bounded Errors of Commission Method

Table 1-16. Comparison of ST Carbon Monoxide Results: 1974 Model Year Fleet, Bounded Errors of Commission Analysis (E_c = constant = 5%)

Short Test	Parameter, %	
	E_o	FF
Federal Short Cycle	7	65
NY/NJ Composite	8	64
Clayton Key Mode (Laboratory)		
Idle	19	53
Low Speed	18	54
High Speed	35	38
Clayton Key Mode (Garage)		
Idle	35	38
Low Speed	35	38
High Speed	37	35
Federal Three-Mode (Laboratory)		
Idle	20	53
Low Speed	20	52
High Speed	29	43
Federal Three-Mode (Garage)		
Idle	35	37
Low Speed	31	41
High Speed	30	42
2500 rpm Unloaded (Laboratory)	19	53
2500 rpm Unloaded (Garage)	33	40

Table 1-17. Comparison of ST NO_x Results: 1974 Model Year Fleet, Bounded Errors of Commission Analysis (E_c = constant = 5%)

Short Test	Parameter, %	
	E_o	FF
Federal Short Cycle	14.5	3
NY/NJ Composite	16.5	1.5
Clayton Key Mode (Laboratory)		
Idle	13.5	<5
Low Speed	14	<5
High Speed	13.5	<5
Federal Three-Mode (Laboratory)		
Idle	14	<5
Low Speed	14	<5
High Speed	14	<5
2500 rpm Unloaded (Laboratory)	14	4

1.2.2.4 Single-Constituent Test Results

On the average, the bag-type tests have lower E_o and higher FF for a fixed rate of E_c than do the volumetric tests. However, FF rates in the 30 percent range can be achieved with any of the tests. For a fixed percent FF, the percent E_o is determined since the sum of FF and E_o is the FTP rejection rate. Thus, the "best" test for fixed percent FF is the one with the lowest percent E_c. In general, the bag-type STs are better in this respect. However, the actual level of percent E_c on the volumetric tests is still quite low. For example, at 30 percent FF on the CO Federal Short Cycle, the percent E_c is essentially zero. For CO on the Key Mode low-speed mode, percent E_c is 0.65 percent for laboratory instruments and 3.85 percent for garage instruments.

1.2.2.5 Multiple-Constituent Tests

In addition to analyzing each pollutant individually, an analysis was made for multiple-constituent tests. The method of analysis and computational procedures were the same as for the CEV fleet, as discussed in Sec. 1.1.2.8.

Three-constituent test results for the Federal Short Cycle and the Federal Three-Mode (high-speed and idle modes only) were computed and graphically summarized as a function of predicted E_c. Table 1-18 summarizes these results using laboratory instruments for predicted E_c values ≤ 2 percent.

For the actual percent E_c less than 2 percent, the laboratory results of the Federal Three-Mode and the Federal Short Cycle are comparable. Table 1-18 indicates the minimum and maximum for percent FF and percent E_o, while percent E_c is less than 2 percent. There is little difference between the idle mode and the Federal Short Cycle. Over this range of percent E_c, the idle mode would appear favorable to the Federal Short Cycle due to the lower value of percent E_c on the idle mode.

Table 1-18. ST Comparison: 1974 Model Year Fleet, Multiple Constituent Tests (Actual $E_c \leq 2\%$)

Short Test	% FF		% E_o	
	Min	Max	Min	Max
Federal Short Cycle	25	36	44	55
Federal Three-Mode				
Idle	22	38	42	58
High	5	42	38	75

A comparison of instrument types showed that the laboratory instruments are generally preferable.

1.3 DEFECT DATA FROM CATALYST-EQUIPPED EXPERIMENTAL VEHICLE FLEET

1.3.1 Nature of Defects and Statistical Impact

Upon completion of the FTP and ST tests performed on the CEV fleet as described in Sec. 1.1, 95 defect tests were performed on 5 of the vehicles from the 40-vehicle CEV fleet.

The 95 defect tests simulated a wide variety of malfunctions which could occur in typical passenger cars. The general categories of defects are defective ignition components; changes in ignition timing, dwell, and spark advance; faulty carburetion; defective valves; clogged air filters; and faulty emission control components. The defects were introduced individually and mixed.

Correlation analyses were performed to determine the statistical character of the defect test data. Many of the defect tests were either replications or produced similar data. The HC correlations are consistently higher, over 0.9, among the defect data than the previous 40-car CEV fleet. Addition of all defect data to the original CEV fleet data would significantly distort the population characteristics with regard to HC. CO and NO_x distortion would also occur, although not as pronounced as with HC.

As the assumption of independence of the observations is crucial to contingency table analysis, the 95 defect tests were statistically pruned to 24 tests representing 24 independent defective vehicles. These data are considered to represent a population distinct from the original 40-car population. Of these 24, 6 had no Federal Three-Mode (laboratory) data, and 5 had no Key Mode (laboratory) data.

1.3.2 Contingency Table Analysis Results

The analysis proceeded in two stages. The original CEV fleet population was first analyzed, using first good data. The analysis method was the bounded errors of commission procedure which established the ST cut-points (see Sec. 1.1.2). Percent E_c was varied from 10 percent to 1 percent in 1-percent increments, with the addition of points at 0.5 percent and 0.1 percent. Immediately following analysis of the original CEV fleet, the defect population was analyzed. The contingency table results were calculated for this population using the cut-points previously determined from the original CEV fleet population. The computations were performed at each of the E_c settings. Thus, the analysis is merely an assessment of how well a test constructed using data with an unknown mix of normal and defect operation will perform on a population of defective vehicles known to represent extreme departures from normal operation. A summary of the analysis on each constituent is given in Table 1-19. The ST cut-points were established for E_c less than or equal to 5 percent, and the FTP level was Level I (HC = 0.41 gm/mi, CO = 3.4 gm/mi, NO_x = 3.1 gm/mi).

1.3.2.1 Hydrocarbon Emission

In all cases, each ST produced significantly higher FF values and lower E_o values for the defect fleet than for the original CEV fleet. The percent E_c for the defect fleet was generally lower and varied from 0.97 to 8.68 percent, as compared with the 5 percent level used in the CEV fleet to select the HC cut-point values.

1.3.2.2 Carbon Monoxide Emission

Each ST produced significantly higher FF values and lower E_o values for the defect fleet than for the original CEV fleet, except for the Unloaded 2500 rpm ST with garage analyzers, where the E_o values were essentially the same. The percent E_c for the defect fleet was generally somewhat higher than the 5 percent level used in the CEV fleet, varying from 4.48 to 16.5 percent.

1.3.2.3 Oxides of Nitrogen Emission

Both FF and E_o values were significantly higher for the defect fleet than for the original CEV fleet, for each ST. The percent E_c for the

Table 1-19. Defect Analysis Comparison Summary: Predicted Population [% E_c = 5,[a] FTP Level I[b]]

Short Test	Test Mode	No. of Defect Cars	Pollutant	Original CEV Fleet		Defect Fleet		
				% E_o	% FF	% E_o	% FF	% E_c
Federal Short Cycle		24	HC	11.0	55.9	5.40	69.0	4.21
			CO	14.1	22.1	6.28	65.2	6.11
			NO_x	9.60	5.36	36.6	16.9	1.22
NY/NJ Composite		24	HC	7.24	59.6	5.31	69.1	6.02
			CO	16.1	20.1	7.85	63.4	9.3
			NO_x	9.77	5.19	18 4	35.19	10.5
Key Mode (Laboratory)	High	19	HC	30.4	36.8	6.47	67.6	2.84
			CO	36.0	7.75	22.2	48.3	11.4
			NO_x	6.87	8.69	8.55	52.2	9.31
	Low		HC	35.3	37 0	6.36	67.7	2.42
			CO	33.0	10.8	17.2	53.2	13.8
			NO_x	13.8	1.76	45.0	15.8	11.3
	Idle		HC	6.79	60.5	6.01	68.1	5.56
			CO	28.6	15.2	10.8	59.7	6.26
			NO_x	13.4	2.20	45.4	15.4	8.34
Key Mode (Garage)	High	24	HC	21.8	45.4	8.02	66.4	3.63
			CO	33.3	10.1	23.9	47.4	12.03
	Low		HC	22.3	44.9	8.16	66.3	5.37
			CO	36.5	6.79	32.0	39.3	16.5
	Idle		HC	10.38	56.8	8.03	66.4	8.68
			CO	29.2	14.1	11.7	59.6	7.29
Federal Three-Mode (Laboratory)	High	18	HC	10.8	58.1	9.85	71.6	4.74
			CO	43.5	6.10	16.14	52.4	7.48
			NO_x	2.93	8.75	5.65	53.6	6.05
	Low		HC	16.9	52.0	10.6	70.8	4.54
			CO	40.9	8.68	20.1	48.5	10.1
			NO_x	10.9	6.73	50.5	8.78	2.30
	Idle		HC	16.6	52.3	10.5	70.9	6.55
			CO	33.4	16.1	17.0	51.6	10.6
			NO_x	10.6	1.05	54.1	5.17	0.88
Federal Three-Mode (Garage)	High	24	HC	19.5	47.7	8.47	66.0	3.75
			CO	36.1	7.21	23.6	47.7	11.6
	Low		HC	22.0	45.2	8.16	65.8	5.16
			CO	36.5	6.81	30.6	40.7	13.7
	Idle		HC	18.0	49.1	6.81	67.6	6.13
			CO	29.2	14.1	12.9	58.4	4.48
2500 rpm Unloaded (Laboratory)		24	HC	38.7	28.5	13.7	60.7	0.97
			CO	34.9	8.46	21.0	50.4	10.3
			NO_x	12.9	1.83	47.7	5.93	2.26
2500 rpm Unloaded (Garage)		24	HC	37.0	30.2	15.0	59.5	1.55
			CO	37.7	5.62	39.9	31.37	8.74

[a] E_c = 5% constant for original CEV fleet

[b] HC = 0.41 gm/mi
CO 3.4 gm/mi
NO_x 3.1 gm/mi

defect fleet was generally higher than the 5 percent level used in the CEV fleet, varying from 0.88 percent to 11.3 percent.

1.3.2.4 Multiple-Constituent Tests

The results of a three-constituent test for the Key Mode (laboratory) and a nine-constituent test for the Key Mode (laboratory) are shown in Table 1-20. These results are typical for all the multi-constituent test analyses made. As can be seen, the multiple-constituent ST had noticeable improvements in FF discrimination over values obtained for the original CEV fleet, with essentially no E_c.

Table 1-20. Key Mode Composite Test[a] (Laboratory Data)

Test Type	Original CEV Fleet			Defect Fleet		
	% FF	% E_c	% E_o	% FF	% E_c	% E_o
Three-Constituent						
High Speed	27.5	5.00	37.5	89.5	0	10.5
Low Speed	22.5	5.00	42.5	73.7	0	26.3
Idle	60.0	5.00	5.00	89.5	0	10.5
Nine-Constituent	62.5	12.50	2.50	94.7	0	5.26

[a] % $E_c \leq 5$; FTP Level I (HC = 0.41 gm/mi, CO = 3.4 gm/mi, NO_x = 3.1 gm/mi)

1.3.2 5 General Comments

A review of the above typical results illustrates that the short tests perform well at isolating a population of defective cars. This is noted by the general tendency for percent FF to increase and percent E_o to decrease in the defect population. Although percent E_c decreased for HC, this was not generally true for CO and NO_x.

The sources of the errors of commission and omission are twofold. The first and usual source is that of the test procedures; i.e., measurement errors. The second source is due to mixing of defects. An observation was classified as a defective car if any component of the vehicle was defective. Hence, all the NO_x data analyzed are not representative of NO_x defects, for example. The multiple-constituent tests (which tend to eliminate mixing errors) show a very high probability, greater than 70 percent, of detecting defect vehicles (note that all the defective cars failed the FTP at Level I).

In conclusion, the ST/FTP tracking of defective vehicles is very good.

1.4 GENERAL OVERVIEW REMARKS

1.4.1 Mode vs Bag ST

1.4.1.1 Individual Pollutants

In all the analyses conducted, the bag tests were shown to be technically superior in analyzing HC and CO. Mode-type STs are preferable to bag STs when considering their relative performances on NO_x. However, all STs are deficient in analyzing NO_x. As the dominant variables in both fleets are HC and CO, the bag tests are preferable under these conditions.

The complexity of implementation of bag-type STs could be a major deterrent to their universal acceptance. The mode STs are more desirable in this respect, especially if garage-type instruments are deemed suitable. A clear choice is not possible without a full analysis in which the objectives and constraints of an implementation procedure are specified.

1.4.1.2 Multiple-Constituent Tests

The clear superiority possessed by the bag-type ST is not present when comparing tests on a multiple-constituent basis. In both the CEV fleet and the 1974 model year fleet, the Federal Short Cycle is approximately equivalent to the high-speed mode of the Federal Three-Mode with laboratory instruments.

1.4.2 Single Mode vs Weighted Mode Tests

Analysis of weighted mode tests shows only very minor improvements in correlation over a single-mode ST. As a weighted-mode ST would be of increased complexity, this option demands little attention.

1.4.3 Garage Instrument vs Laboratory Analyzer

The garage instruments offer additional tradeoffs within the volumetric test area. Garage instruments reduce the technical sophistication of the ST while, at the same time, reducing the complexity of implementation. Technically, the garage instrument tests are inferior to the laboratory instrument tests in that the garage instruments have higher percent testing errors for a given modal test. However, they provide additional options under a full-scale tradeoff study.

1.4.4 Correlation Coefficient vs Contingency Table Analysis

The usefulness of the correlation coefficient is confined to measuring direct relatability. It is useful in identifying critical areas for further research and in providing a relative overview, such as ranking of the ST.

For analyzing the tradeoff between impact on air quality and cost to the public, a contingency table analysis which admits a policy decision is most favorable. The public costs are defined as those incurred by the manufacturer and/or those incurred by the environment. Constraints are easily incorporated and, thus, an appropriate policy or set of policies can be identified. The method of bounded errors of commission is recommended as the procedure for contingency table analysis. The policy decision is the bound on percent of allowable errors of commission. The effect of the policy is measured in percent FF and percent errors of omission. Other measures such as relative impact, discussed below, are also available. In short, it allows the policy-maker to control quantifiable economic costs and to assess the impact on air quality.

1.4.5 Relative Impact on Air Quality

1.4.5.1 By Individual Pollutant

The FTP standards, or cut-points, can be interpreted as establishing the desired impact on air quality in that the FTP cut-points fix the percent of the population classified as high-polluting vehicles. If the FTP were used as the test procedure in an inspection/maintenance program which tested all vehicles (i.e., as the ST), the relative impact on air quality would ideally be 100 percent; that is, all the vehicles that are failures are in fact identified as such.

Similarly, the effectiveness of the various STs can also be used as a measure of impact on air quality, where "ST effectiveness" is defined as:

$$\text{ST effectiveness} = \frac{\%\ \text{FF for the short test}}{\%\ \text{FTP failures in same population}} \qquad (1\text{-}1)$$

$$= \frac{\%\ \text{FF}}{\%\ \text{FF} + \%\ E_o}$$

Thus, on this basis, the ST is always less effective than the FTP, in proportion to the percent of errors of omission (E_o) associated with a given ST. Table 1-21 shows the ST effectiveness values for the 1974 model year fleet for an E_c rate of 5 percent. These values indicate the relative impact on air quality of the ST as compared with the impact of the FTP on air quality, for the E_c conditions shown.

Actual benefit or impact is dependent upon the user's needs and constraints. One measure of benefit would be the tons of pollutant removed from the atmosphere on an annual basis in a given region by the use of an ST in an inspection/maintenance program. This can be approximated by the relationship:

$$\text{Tons removed} = \text{ST effectiveness} \times \Delta\ \text{pollutant to be removed in population} \times \%\ \text{population sampled} \qquad (1\text{-}2)$$

Table 1-21. Short Test Effectiveness; E_c = 5%
1974 Model Year Fleet

Short Test	ST Effectiveness[a]			%FF		
	HC	CO	NO_x	HC	CO	NO_x
Federal Short Cycle	0.83	0.90	0.17	34	65	3
NY/NJ Composite	0.78	0.88	0.06	32	64	1
Key Mode						
Laboratory	0.58	0.76	0.28	24 (I)[b]	55 (L)	5 (I)
Garage	0.34	0.51		14 (L)	37 (H)	
Federal Three-Mode						
Laboratory	0.61	0.72	0.22	25 (I)	52 (I)	4 (H)
Garage	0.41	0.48		17 (I)	35 (I)	
2500 rpm Unloaded						
Laboratory	0.61	0.73	0.22	25	53	4
Garage	0.39	0.47		16	34	

(a) $\text{ST Effectiveness} = \frac{\text{\% FF}}{\text{FTP Fails}}$

where

FTP HC Fails = 41.09%

FTP CO Fails = 72.35%

FTP NO_x Fails = 17.8%

(b) I = idle mode

L = low speed mode

H = high speed mode

where

$$\text{ST effectiveness} = \frac{\%\ FF}{\%\ FF + \%\ E_o}$$

and

Δ pollutant to be removed in population = average value for the population of HC, CO, or NO_x, in tons/year, in excess of that permitted by the FTP standard; it is based on the FTP failures and corresponding emission values observed in the population, and vehicle-miles-traveled characteristics

This relationship ignores those additional benefits likely to occur if the failed vehicles were repaired and achieved emission levels below the FTP standards after repair.

Equation (1-2) indicates areas of tradeoff that should be examined prior to the implementation of a specific inspection/maintenance program. Figure 1-9 depicts one aspect of such tradeoffs. This figure is an illustrative plot of Eq. (1-2) for two different ST (Federal Short Cycle, and Unloaded 2500 rpm with garage instruments) as used for CO emissions. As indicated in Table 1-21, their effectiveness values are 0.90 and 0.47, respectively; i.e., as compared with the CO discrimination capability of the FTP procedure, they are 90 and 47 percent as effective as the FTP in identifying vehicles which fail the FTP test on CO. Thus, to achieve the same benefit in total CO pollutant removal, the percentage of the population that must be sampled by the Unloaded 2500 rpm ST is approximately double that which must be sampled with the Federal Short Cycle ST. Alternatively stated, for any given percent sampling of the population, the use of the Federal Short Cycle ST would result in approximately double the amount of CO removed.

The complexity of program implementation can be measured in annual cost. The cost components would include such items as annual

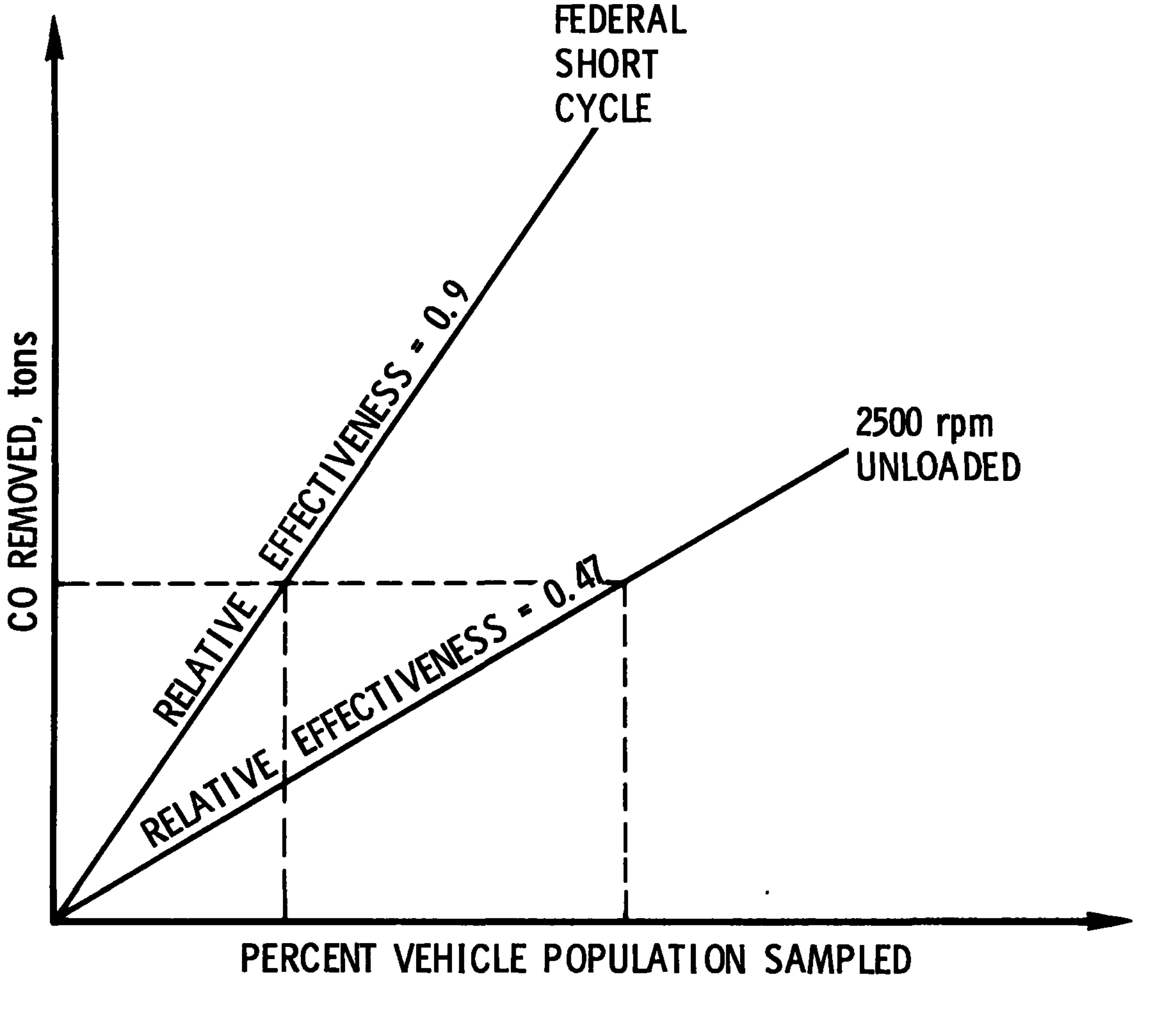


Figure 1-9. Impact of Percent Population Sampled on CO Removed (Illustrative Example Only)

operating expenses, maintenance expenses, and amortized initial development and installation expenses. The ST requiring laboratory instrumentation would have substantial initial procurement costs, and higher annual maintenance and operating expenses than those using garage instruments. The bag-type ST requires more skilled personnel and a CVS station. The bag ST and multi-mode tests also require a dynamometer. Thus, the ST can be ranked according to cost as follows:

- Federal Short Cycle, NJ/NY Composite
- Three-Mode volumetric with laboratory instruments
- Three-Mode volumetric with garage instruments
- 2500 rpm Unloaded with laboratory instruments
- 2500 rpm Unloaded with garage instruments

For those inspection/maintenance programs targeted to 100 percent inspection of all vehicles, the above ranking of ST by cost would appear valid. However, if less than 100 percent inspection is envisioned for some reason, then additional factors should be considered. For example, the unit cost of a program (per vehicle) would be expected to decrease as the percent of the population sampled increases. Thus, in the example of Figure 1-9, if the program were targeted to a defined level of CO removal, a cost-benefit analysis might be an appropriate method to select the ST and the percentage sampled for minimum cost purposes. The type of constraint normally imposed on a tradeoff study would typically be total annual cost; however, additional constraints on percent E_c or percent rejected (E_c plus FF) are also admissible under this approach. Other areas of consideration are effective sampling and site selection, importance of the pollution source as a function of geographic location, social impact, etc.

1.4.5.2 Multiple Constituent Tests

Short test effectiveness is also a useful measure of test quality for the multiple-constituent test, although the pollutant removal implications of Eq. (1-2) must apply on an individual pollutant basis. Shown in Table 1-22

Table 1-22. Short Test Effectiveness Values for Multiple Constituent Tests; 1974 Model Year Fleet[a]

Short Test	ST Effectiveness	Percent E_c	
		Predicted[b]	Actual
Federal Short Cycle	0.77	5	8.84
	0.373	0.05	2.04
	0.314	0.01	0.68
Federal Three-Mode (Laboratory Instruments)			
Idle	0.483	5	0.00
High	0.568	5	2.72
Federal Three-Mode (Garage Instruments)			
Idle	0.330	5	0.00
High	0.374	5	0.69

[a]FTP failures = 80%

[b]Using bounded errors of commission method of analysis

are the effectiveness values for the Federal Short Cycle and the Federal Three-Mode. Comparison of the test-to-test effectiveness values should, of course, be made at points where the actual percent E_c is equal; however, this can be only approximated with the existing data.

The technical favorability of the Federal Short Cycle is diminished when comparing on the basis of equivalent percent E_c. Although the Federal Short Cycle effectiveness is 0.77 at actual percent E_c equal to 8.84, it is reduced to 0.373 and 0.314 for actual percent E_c values of 2.04 and 0.68, respectively. However, as shown in Table 1-22, the effectiveness values of the high-speed mode of the Federal Three-Mode ST with laboratory and garage instruments are 0.568 (actual percent E_c = 2.72) and 0.374 (actual percent E_c = 0.69), respectively. Comparable effectiveness values for the idle mode with laboratory and garage instruments are 0.483 and 0.330, respectively, both with actual percent E_c equal to 0. Thus, in the actual percent E_c range below approximately 3, the Federal Three-Mode ST with garage instruments (idle or high-speed mode) is essentially equivalent to the Federal Short Cycle in effectiveness while the Federal Three-Mode ST with laboratory instruments has a higher effectiveness than the Federal Short Cycle.

Although the favorability of the laboratory instruments over the garage instruments persists under this method of comparison, consideration of program complexity could bias test desirability in favor of the Federal Three-Mode with garage instruments.

2. INTRODUCTION

2. INTRODUCTION

2.1 BACKGROUND AND OBJECTIVES

With regard to compliance by vehicles and engines in actual use with the certification emission standards established for a vehicle at the time of its manufacture, the Clean Air Act of 1970 stipulates in Sec. 207 (b):

"If the Administrator determines that

(i) there are available testing methods and procedures to ascertain whether, when in actual use throughout its useful life .... , each vehicle and engine to which regulations .... apply complies with the emission standards of such regulations,

(ii) such methods and procedures are in accordance with good engineering practices, and

(iii) such methods and procedures are reasonably capable of being correlated with tests conducted under section 206 (a) (1), then --

> "(1) he shall establish such methods and procedures by regulation, and
>
> "(2) at such time as he determines that inspection facilities or equipment are available for purposes of carrying out testing methods and procedures established under paragraph (1), he shall prescribe regulations which shall require manufacturers to warrant the emission control device or system of each new motor vehicle or new motor vehicle engine .... for its useful life."

Thus, there are the essential requirements of "availability," "conformance with good engineering practices," and "reasonable correlation with certification test procedures" which must be met prior to the promulgation of regulations which impose the in-use warranty provisions of Sec. 207 (b) upon the motor vehicle manufacturers.

The states of New York and New Jersey have developed short emission tests for potential use in inspection/maintenance (I/M) programs in their areas. The Clayton Manufacturing Company also developed a short test procedure for use in I/M programs. More recently, the EPA has developed short tests similar to those of New York, New Jersey, and Clayton. Thus, there are a number of tests "available" to determine the exhaust emissions of in-use vehicles; these test methods and procedures "conform with good engineering practices" in that they utilize well-recognized emission-measurement equipment and techniques.

These tests are "short" in duration (approximately 3 to 5 minutes) in order to (a) minimize the inconvenience of the motoring public (and thereby maximize cooperation), and (b) minimize capital costs of inspection stations by maximizing the number of vehicles a given facility could test. They have been structured for "simplicity" in order to (a) reduce the potential for procedural errors, and (b) to reduce test costs. As a result, all such tests require that the vehicle be tested in a "hot" condition; i.e., at its normal operating temperature.

There remains the requirement to demonstrate "reasonable correlation with certification test procedures," i.e., with the Federal Test Procedure (FTP) used in the certification of new motor vehicles. Therefore, the present study was performed with the principal objective of analyzing emission data from both short tests (STs) and FTP tests of the same vehicles in order to determine the degree of "correlation" which exists between vehicle exhaust emissions as determined by an ST and the FTP. A second objective was to analyze continuous trace data from these tests to form the basis for the development of a new and "better correlating" short test procedure, should the need occur.

2.2 STUDY SCOPE

The basis for the analyses was ST and FTP data from three vehicle fleets:

a. <u>Catalyst-Equipped Experimental Vehicle (CEV) Fleet</u>

This fleet comprised 40 catalyst equipped "1975-prototype" models that had been operated in California in Ford vehicle test programs. These vehicles were tested by Olson Laboratories in Anaheim, California.

b. <u>In-Use 1974 Model Year Vehicle Fleet</u>

This fleet comprised 147 in-use 1974 model year cars in three groups of approximately 50 cars each, representing different inertia weight classes (subcompact, intermediate, and full size) and three different auto manufacturers. These vehicles were procured by Olson Laboratories, Livonia, Michigan, from the greater Detroit area and tested by EPA in the Ann Arbor test facility.

c. <u>Defect Test Fleet</u>

This fleet comprised five of the catalyst-equipped Ford vehicles from the CEV fleet noted above. Approximately 95 "defect" tests were conducted on these vehicles. The defect tests included such items as spark plug misfiring, carburetor misadjustment, defective valves, and degraded catalysts. These tests were performed by Olson Laboratories, Anaheim, California.

Each of the above vehicles was tested by the FTP and the following STs:

- Federal Short Cycle
- NY/NJ Composite
- Clayton Key Mode
- Federal Three-Mode
- Unloaded 2500 rpm

For the volumetric-type tests (Clayton Key Mode, Federal Three-Mode, and Unloaded 2500 rpm), both laboratory and garage-type instruments were used to record HC and CO measurements. Garage-type instruments were included in the event that higher-accuracy laboratory analyzers would not be compatible with the working environment of a typical automotive garage or a large-scale vehicle testing station. All the NO_x readings were made with laboratory analyzers due to the unavailability of an appropriate garage-type NO_x instrument.

2.3 METHOD OF APPROACH

The primary thrust of the work performed under this contract was statistical in nature. Two complementing methods were employed to assess Sec. 207 (b) correlation -- a conventional correlation analysis and a contingency table analysis. The conventional correlation analysis addresses the question of direct relatability between the ST and the FTP by examining the relationships present in the data. The results are of great usefulness in indicating the extent to which each ST tends to track the FTP. The contingency table analysis addresses the relatability of ST and FTP on a pass-or-fail level. Each data point is examined, and a determination is made as to whether the auto passed or failed the FTP and passed or failed the ST. Thus, errors of commission (E_c), errors of omission (E_o), correct passes by each test (PP), and correct fails by each test (FF) are identified. Hence the technique allows for the study of the tradeoffs between errors and correct identifications.

The conventional correlation analysis, being purely an analysis of the data, does not permit policy decision as a variable or parameter. Contingency table analysis, on the other hand, permits the integration of policy decision in that it provides for the determination of the ST pass/fail cut-points. Thus, policy decision entered the analysis as a quantifiable variable, and a study indicating the impact of various policies was performed in the contingency table analysis. One important method reflecting impact to policy is that of the method of bounded errors of commission. In this scheme, limits are set on the maximum permissible percentage of errors of commission, and the ST cut-points are selected to yield minimum errors of omission within this constraint. This analysis permits a direct answer to the question, "For a given permissible level of errors of commission, what level of errors of omission is associated with a given test, and with what impact on air quality (inferred from the percentage of FF and E_o vehicles)?"

These two methods of analysis, each representing different interpretations of Sec. 207 (b) correlation, were applied to both the CEV fleet and the 1974 model year in-use fleet. They were also applied to the defect test fleet to (a) determine the statistical character of the specific defect tests, and (b) to examine the ability of the STs to detect defective vehicles of this nature.

2.4 ORGANIZATION OF REPORT

The results of the study are reported in the following order and context:

Section 3 - Test Characteristics and Procedures

Defines the five short tests used, describes the test conditions and procedures, and discusses the composition of the three test fleets.

Section 4 - Catalyst-Equipped Experimental Vehicle Fleet

Defines and discusses, for the CEV fleet, the statistical analysis techniques and results for the correlation and contingency table analyses conducted.

Section 5 - In-Use 1974 Model Year Vehicle Fleet

Defines and discusses, for the 1974 model year fleet, the statistical analysis techniques and results for the correlation and contingency table analyses conducted.

Section 6 - Defect Data from Catalyst-Equipped Experimental Vehicle Fleet

Defines and discusses the analysis techniques and results from the analyses made to determine the statistical character of the defect tests and to examine the ability of the various short tests to detect defective vehicles.

3. TEST CHARACTERISTICS AND PROCEDURES

3. TEST CHARACTERISTICS AND PROCEDURES

In this program, five short tests (STs) and the 1975 Federal Test Procedure (FTP) were performed on three test fleets. This section defines the various STs, describes the test conditions, and discusses the composition of the test fleets.

3.1 SHORT TESTS

3.1.1 General

Two classes of STs were involved, and these may be categorized as (a) modal or volumetric and (b) as driving trace or CVS. Both sets of nomenclature are used in this report, depending upon the aspect of the test structure that is pertinent to the discussion. In the modal tests, the test technician operates the vehicle on a dynamometer at a fixed vehicle speed and dynamometer load, or unloaded at a fixed engine rpm, or at idle. The vehicle tailpipe exhaust is sampled directly, and the concentration of each pollutant is measured and recorded in percent, or in parts per million, of the undiluted exhaust. Three modal STs were used:

- Clayton Key Mode
- Federal Three-Mode
- Unloaded 2500 rpm

The Clayton Key Mode and Federal Three-Mode STs each had high speed, low speed, and idle modes.

For the second class of ST, the test technician drives the car on the dynamometer in accordance with a prescribed driving pattern on a driving trace. The vehicle exhaust is diluted by the CVS procedure, and a single sample bag of diluted exhaust is collected for the whole ST. The dilute sample is analyzed and the results usually expressed in grams per mile. This procedure requires the same equipment, sampling procedure, and analytical equipment as the Federal Test Procedure (FTP) used in the certification of new vehicles. The difference is that the driving trace for the ST is much shorter and simpler. Two CVS-type STs were used:

- Federal Short Cycle
- Composite of New Jersey Acid and New York Short Test (NY/NJ)

Both classes of ST involved approximately 2 or 3 minutes of driving time on the dynamometer. All STs were performed with the engine at its normal operating temperature; i.e., "hot" tests.

The HC and CO content of the exhaust gas in the volumetric tests was measured from samples taken at the same time by two different classes of instruments. One set, called "laboratory analyzers," was identical (except for range) with the high-accuracy analyzers used in CVS certification testing. The second set, called "garage instruments," used a lower-cost, lower-accuracy and precision instrument of the type currently in use by many automotive service stations for routine diagnostic work. The structure of each test is given below.

3.1.2 ST Definition

3.1.2.1 Clayton Key Mode

The Clayton Key Mode is a well-known test which has been in use for several years for diagnostic emissions testing.

Vehicle Weight Class, lb	Transmission Range/Gear	Dynamometer Load, hp @ mph	Modes: High Speed Cruise, mph	Modes: Low Speed Cruise, mph	Modes: Idle
2000 to 2750	In lower gear (3rd)	15 @ 38	36 to 38	22 to 25	Automatic transmission drive
2800 to 3750	Drive or high gear	24 @ 46	44 to 46	29 to 32	
3800 and up	Drive or high gear	30 @ 50	48 to 50	32 to 35	

3.1.2.2 Federal Three-Mode

The Federal Three-Mode differs from the Clayton Key Mode in that it uses dynamometer loadings simulating the average power that occurs at the appropriate speeds in the FTP where the vehicle is accelerating (decelerations are not included). This results in a higher dynamometer loading for the Three-Mode as compared with the Key Mode at the low speed condition, and, for vehicles with an inertia weight greater than 4500 lb, at the high speed setting also.

Vehicle Weight Class, lb	Transmission	High Speed Mode		Low Speed Mode		Idle Mode
		Speed, mph	Load, hp	Speed, mph	Load, hp	
Up to 2500	In lower gear for 30-mph test (3rd gear)	50	21	30	9	Automatic transmission in neutral
2501 to 3500	Drive or high gear	50	26	30	12	
3501 to 4500	Drive or high gear	50	31	30	15	
Above 4500	Drive or high gear	50	36	30	18	

3.1.2.3 Unloaded 2500 rpm

This is a high-speed test: 2500 rpm, transmission in neutral.

3.1.2.4 Federal Short Cycle

The Federal Short Cycle was derived from the FTP. Accelerations and decelerations are representative of those encountered in the FTP, and average speed is nearly the same as the three-bag FTP driving cycle (21.70 mph and 21.27 mph, respectively).

This is a nine-mode, 125-sec CVS test that follows the driving schedule shown below and plotted in the top half of Figure 3-1.

Mode	Time in Mode, sec
0 - 16 mph acceleration	6
16 - 29 mph acceleration	23
29 mph cruise	10
29 - 37 mph acceleration	18
37 - 42 mph acceleration	4.5
42 - 37 mph deceleration	2.5
37 - 20 mph deceleration	32
20 - 0 mph deceleration	7.5
Idle	21.5
	125.0

The test does not include engine startup or shutdown. The dynamometer loadings follow the procedure as required for the FTP.

3.1.2.5 Composite NY/NJ

This is a six-mode, 75-sec CVS test that follows the driving cycle shown below and plotted in the lower half of Figure 3-1.

Mode	Time in Mode, sec
Idle	22
0 - 30 mph acceleration	15
30 mph cruise	15
30 - 10 mph deceleration	12
10 mph cruise	7
10 - 0 mph deceleration	4
	75

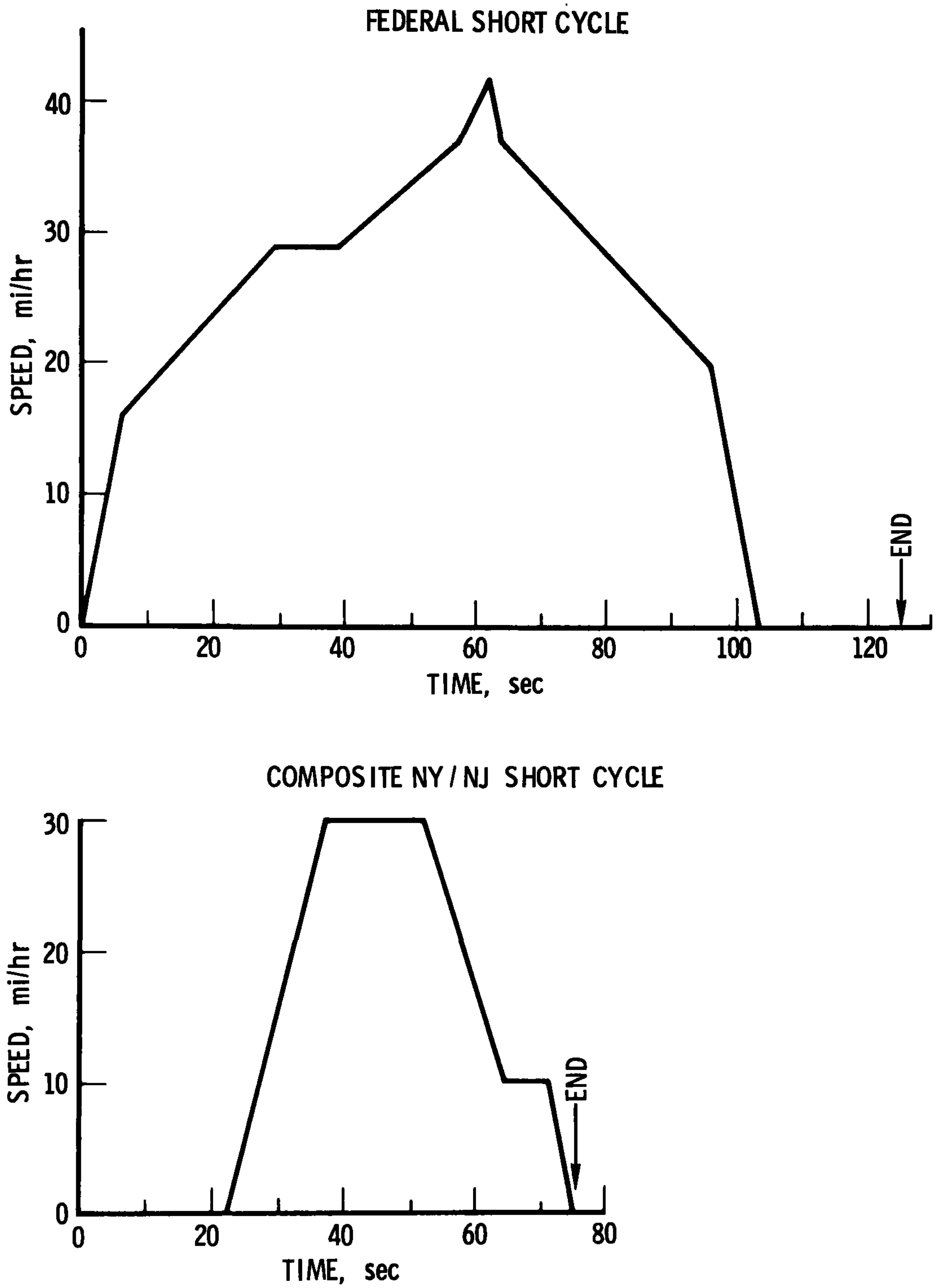


Figure 3-1. Federal Short Cycle and Composite NY/NJ Short Cycle Test Driving Schedules

The test does not include engine startup or shutdown. All vehicles are tested at an inertia weight of 3000 lb and a dynamometer loading of 3.5 hp at 30 mph.

3.1.3 Short Test Sequence

A short test sequence consists of the following tests and soak periods in the order shown.

a. Completion of 1975 FTP
b. Soak - 6 minutes
c. Clayton Key Mode
d. Soak - 6 minutes
e. Federal Three-Mode
f. High-speed Unloaded 2500 rpm test
g. Soak - 6 minutes
h. Federal Short Cycle
i. Soak - 6 minutes
j. Composite NY/NJ

The 6-minute soak procedure is performed as follows: after completion of the preceding test, the vehicle engine is stopped, the vehicle hood is closed if it was open, and the auxiliary air cooling fan is turned on if it was not previously in use. The fan remains in operation for 3 minutes. At the end of 3 minutes, the auxiliary air fan is turned off and the vehicle's engine is started. The engine is allowed to idle in neutral for 3 minutes. Upon the completion of this 3-minute idle period, the next test in the sequence is initiated.

During the entire ST, the vehicle hood is closed and the auxiliary cooling fan is not in operation.

In the modal tests, the car is to be operated in each mode until the emissions stabilize. In the CVS tests, driving trace procedures and tolerance (and transmission shift points, if applicable) are the same as for the FTP.

3.2 TEST FLEETS

3.2.1 Catalyst-Equipped Experimental Vehicle Fleet (CEV)

3.2.1.1 Type of Car

These 40 vehicles were all 1973 Ford Galaxies, owned by the Ford Motor Company. They were equipped by Ford with an oxidizing catalyst for control of HC and CO. The emission control system also included air injection and exhaust gas recirculation (EGR). All had 8-cylinder, 400 CID engines with two-barrel carburetors and automatic transmissions. Manufacturer's specifications for ignition timing and dwell were 12° BTDC and 24° to 30°, respectively. Axle ratio was 3.0, and tire size was HR 78-15. The FTP inertia weight at which the vehicles were tested was 5000 lb.

3.2.1.2 Prior Use

At the time of receipt of these vehicles by the testing laboratory (Olson Laboratories, Inc., Anaheim, California), the odometer readings ranged from 7000 to 36,000 miles, with an average of 21,000. Prior to these tests, the cars were primarily used by Federal and California state employees in a number of locations throughout California. The driving pattern was highly variable, ranging from primarily stop-and-go city traffic to primarily high-speed highway driving. Vehicle and emission system maintenance was performed essentially in accordance with Ford Motor Company recommended procedure. Emission system maintenance on some vehicles was performed by Ford Motor Company, while for others it was performed by local Ford dealers or motor pool personnel, following procedures established and monitored by Ford Motor Company.

3.2.1.3 Test Conditions

Upon receipt of a vehicle, the as-received fuel was drained and test fuel (indolene clear) was added. The car was operated for approximately 10 minutes, at which time a vehicle inspection was performed. This consisted primarily of measuring engine tune, idle CO and HC, inspecting fluid levels, and verifying the existence and operation of emission control devices.

For the first 20 vehicles of this fleet, a short test sequence (as defined in Sec. 3.1.3) was performed right after this inspection, after which the vehicle was placed in cold soak for the first FTP. Immediately following the FTP, another short test sequence was performed, and the vehicle placed in cold soak for the second FTP. A third short test sequence was performed immediately upon completion of the second FTP. For the latter 20 cars of this fleet, the first short test sequence (after the vehicle inspection) was deleted.

All test conditions, instrumentation, and procedures for the 1975 FTP were as prescribed in the Federal Register, with one addition. The concentrations of HC, CO, NO_x, and CO_2 in the undiluted exhaust were also continuously measured and recorded during each FTP. The sampling train and analyzers used for this were the same as those used for the volumetric short test cycles. These continuous trace data were used to gain insight into the emission generation characteristics of various portions of the FTP.

The first group of 20 cars was tested during the period 8 September to 25 October 1974. A group of 10 cars was tested between 11 and 16 December 1974. A final group of 10 cars was tested between 22 January and 19 February 1975.

3.2.2 Defect Test Fleet

Upon completion of the CEV fleet vehicle tests described above, 95 defect tests were performed on 5 of the 40 vehicles of the CEV fleet. These simulated a wide variety of malfunctions that could occur in a typical passenger car: defective ignition components; changes to ignition timing, dwell, and spark advance; faulty carburetion; defective valves; clogged air filters; and faulty emission control components. A detailed listing of all defects is given in the Appendix.

For each defect, one FTP was performed, followed by a short test sequence. For each FTP, additional continuous trace recordings were made of the concentration of HC, CO, NO_x, and CO_2 in the undiluted vehicle exhaust, as was described for the normal vehicle tests. In 20 of the tests, catalyst bed temperature and exhaust flow rate were measured and recorded for the duration of the FTP and each ST.

3.2.3 In-Use 1974 Model Year Vehicle Fleet

3.2.3.1 Types of Cars

This fleet comprised in-use 1974 model year vehicles. There were 49 Ford Pintos, 49 Chevrolets (Caprice and Impala), and 49 Dodge/Plymouths (Coronet, Charger, Satellite). The Pintos were 140 CID, tested at 2750-lb inertia weight, the Dodge/Plymouths were 318 CID, tested at 4000-lb inertia weight, and the Chevrolets were 400 CID, tested at 5500-lb inertia weight.

All cars had automatic transmission. The emission control systems were EGR plus air injection for the Chevrolets and Pintos, and EGR for the Plymouth/Dodges.

The rear axle ratio was 2.73 for the Chevrolets and 3.40 for the Pintos. The Plymouth/Dodges had a ratio of 2.94.

3.2.3.2 Prior Use

These vehicles were all privately owned, and were from the greater Detroit metropolitan area. The as-received odometer readings ranged from 3000 to 20,000 miles, with an average of 11,000. There was no significant difference in the odometer readings between any of the manufacturers' subgroups of 49 cars. No information is available concerning the detailed driving pattern or maintenance history for any of the cars.

3.2.3.3 Test Conditions

Testing was performed by the EPA Emissions Laboratory at Ann Arbor. Each car was tested once by the 1975 FTP, immediately after which a short test sequence (as defined in Sec. 3.1.3, with one exception) was performed. The one exception pertains to the Key Mode test. For the 1974 model year fleet, the Key Mode tests were run at a fixed set of speeds. These speeds were 48 to 50 mph for the high speed mode, and 32 to 34 mph for the low speed mode, regardless of the test vehicle inertia weight. Thus, the Pintos were the only vehicles affected, as all other vehicles fall in the same weight class for the Key Mode test. The Key Mode tests for both the 1974 model year fleet and the CEV fleet were thus all run at the same sets of speeds. The dynamometer inertia and horsepower settings were made in accordance with the test vehicle inertia weight, per the standard Key Mode format.

Twenty-five of the cars that failed the FTP were tuned by EPA and retested by the same procedure described above. This tuneup was parametric in that adjustments were made as required in an effort to bring ignition timing, dwell, etc., within manufacturer's specifications, but no new components were installed, regardless of the condition of the existing ones.

4. CATALYST-EQUIPPED EXPERIMENTAL VEHICLE FLEET

4. CATALYST-EQUIPPED EXPERIMENTAL VEHICLE FLEET

This section summarizes the results of statistical analyses conducted to determine the degree of correlation existing between the various short tests (STs) and FTP tests conducted on the catalyst-equipped experimental vehicle (CEV) fleet. Preliminary analyses are discussed in Sec. 4.1; the principal statistical analysis techniques and results are summarized in Sec. 4.2.

4.1 PRELIMINARY STATISTICAL ANALYSES

Preliminary analyses were made to assess data quality and statistical structure. Of specific concern were the following goals:

a. Determine the data acceptable for further processing.
b. Determine the variation within each test procedure.
c. Determine the vehicle-to-vehicle variation.
d. Determine the intrinsic variables and statistical structure of each of the tests.
e. Determine the distribution properties of the test data.

Goals a and e were met by simple data screening techniques. A multivariable analysis of variance was used to meet goals b and c, while d was addressed by a canonical correlation analysis. These techniques/analyses are briefly discussed below.

4.1.1 Data Screening

All of the basic test data for the CEV fleet were received by The Aerospace Corporation for processing. A screening procedure was developed to evaluate these data, and to provide an annotated data base for subsequent statistical analyses. All inputs to the statistical data base were derived directly from the test data traces. All apparent anomalies and/or discrepancies in the data were examined and an effort made to reconcile them. Discussions were held with the testing laboratory and with EPA/ECTD, as appropriate, to resolve these situations. In some cases, certain tests, or portions thereof, were deleted from the data base. Of the 40 cars of the CEV fleet, the final data base contained 26 cars with two valid FTP tests, and 14 cars with one valid FTP test. A few short test (ST) results were deleted, as were various isolated values for a given pollutant for a specific mode.

After the test data were put on tape, various descriptive characteristics of the data were used to detect gross errors in the observations, in coding and keypunching, and in including inappropriate cases. Generally, this was accomplished by checking for improper symbols or characters, such as characters were numbers should be, for outliers or blunders, and for missing observations. Erroneous data were reconstructed where possible; otherwise, the case was flagged as inappropriate for processing. Table 4-1 summarizes the number of cases available for statistical analysis.

Table 4-1. Number of Cases Available for Statistical Analysis (CEV Fleet)

Test	No. of Cases
Federal Test Procedure	40
Federal Short Cycle	39
NY/NJ Composite	39
Clayton Key Mode	
Laboratory instruments	40
Garage instruments	40
Federal Three-Mode	
Laboratory instruments	31
Garage instruments	40
2500 rpm Unloaded	
Laboratory instruments	40
Garage instruments	40

The mathematical model employed in the contingency table analysis requires that the data follow a bivariate normal or log-normal distribution. This assumption was checked using a combination of histograms, normal probability plots, and scatter plots (Ref. 4-1). Generally, the log of the data appears normally distributed.

4.1.2 Multivariate Analysis of Variance

A multivariate analysis of variance (Ref. 4-2) with estimation of the variance components (Ref. 4-3) was made for the CEV fleet. The purpose of the analysis of variance is the comparison of means when the data are grouped or classified in one or more ways. The CEV fleet data were grouped according to replication. The groups were termed first good data and second good data, reflecting the original testing sequence. No difference in the data groups was discernible.

The purpose in estimating the variance components is the quantification of multiple sources of variation. The sources of variation identified in the CEV fleet were fluctuations between cars and measurement errors within each test. The results of the variance components analysis are shown in Table 4-2. Since there were 14 cars in the CEV fleet which had only one valid FTP, the number of cars in the analysis of Table 4-2 is less than the number previously indicated in Table 4-1 because replicates are required to analyze variance components.

Normalized dispersion is defined as

$$D = \frac{\text{standard deviation of population (S)}}{\text{population mean (M)}}$$

which is a dimensionless quantity. "D" provides an effective measure of the variability of the population as observed by a test. As the fluctuations between cars are legitimate, a good indicator of test quality is the percent of the variation due to testing (α). This indicator is defined as

$$\alpha = \frac{ST^2}{S^2} \times 100$$

Table 4-2. Summary of Variance Components (CEV Fleet)

Test	No. of Cars[a]	Test Mode	Pollutant[a]	M	Units	D	σ, %
FTP	26		HC	0.69	gm/mi	0.88	3
			CO	2.68	gm/mi	0.5	7
			NO_x	2.57	gm/mi	0.26	16
Federal Short Cycle	25		HC	0.59	gm/mi	1.15	22
			CO	1.06	gm/mi	0.88	44
			NO_x	3.70	gm/mi	0.23	30
NY/NJ Composite	25		HC	31.7	ppm	1.49	19
			CO	25.4	ppm	1.27	76
			NO_x	27.0	ppm	0.26	53
Key Mode	25_L 26_G	High speed	HC_L	199	ppm	0.47	10
			HC_G	38.3	ppm	0.35	30
			CO_L	0.043	%	0.70	3
			CO_G	0.046	%	0.42	32
			NO_x	831	ppm	0.58	4
		Low speed	HC_L	181	ppm	0.43	3
			HC_G	38.6	ppm	0.54	65
			CO_L	0.012	%	0.83	1
			CO_G	0.03	%	0.23	84
			NO_x	1418	ppm	0.19	27
		Idle	HC_L	289	ppm	1.0	1
			HC_G	39.8	ppm	0.54	70
			CO_L	0.0075	%	0.64	12
			CO_G	0.024	%	0.25	--
			NO_x	193	ppm	0.27	20
Federal Three-Mode	17_L 26_G	High speed	HC_L	195	ppm	0.65	6
			HC_G	36.6	ppm	0.29	28
			CO_L	0.045	%	0.67	3
			CO_G	0.044	%	0.32	50
			NO_x	1008	ppm	0.47	2
		Low speed	HC_L	271	ppm	1.03	67
			HC_G	42.9	ppm	0.54	77
			CO_L	0.018	%	0.67	3
			CO_G	0.033	%	0.33	69
			NO_x	2406	ppm	0.13	14
		Idle	HC_L	202	ppm	1.61	1
			HC_G	38.5	ppm	0.67	57
			CO_L	0.009	%	0.67	4
			CO_G	0.028	%	0.31	--
			NO_x	90.5	ppm	0.19	52
2500 rpm Unloaded	26_L 26_G		HC_L	375	ppm	2.39	4
			HC_G	59.5	ppm	1.66	1
			CO_L	0.021	%	0.81	1
			CO_G	0.038	%	0.45	50
			NO_x	464	ppm	0.30	48

[a] Subscripts L and G denote laboratory and garage analyzers

where

ST = standard deviation of testing errors

S = standard deviation of population.

Missing values for α in Table 4-2 indicate the computationally degenerate case where ST^2 is computed to be larger than S^2. The α values shown in Table 4-2 indicate that the garage analyzers are of lower quality (higher α) than the corresponding laboratory instruments. The ST bag tests have higher α than many of the volumetric test procedures using laboratory instruments. The high α in the bag tests may be due to variations within the driving procedure rather than to instrumentation, while the low α associated with volumetric tests with laboratory analyzers may be due to simplicity of the procedure plus instrument accuracy.

4.1.3 Canonical Correlation Analysis

Canonical correlation analysis (Refs. 4-2, 4-4) examines the relationship between two sets of variables. The problem is to find a linear combination of a set, X, of variables that has maximum correlation with a linear combination of another set, Y, of variables. The resulting correlation is called the canonical correlation coefficient, and the linear combinations are termed the canonical variables. A second pair of linear combinations is then looked for that has a maximum correlation and is uncorrelated with the first pair of linear combinations. The number of pairs of linear combinations of the X and Y sets is equal to the number of variables in the smaller set (X or Y, whichever is smaller). The technique is useful in testing for independence of two sets of variables and in predicting information about a hard-to-measure set of variables from a set that is easier to measure.

The canonical correlation coefficients for each ST versus the FTP are shown in Table 4-3 together with original correlation coefficients. The observations used were the first good data set. For the EPA Short Cycle and the NY/NJ Composite, the canonical correlation coefficients do not differ significantly from the correlation coefficients of the original data. Slight improvements can be seen in the three-mode volumetric tests. However, the

Table 4-3. Canonical Correlation Coefficients Between the FTP and ST for the CEV Fleet (first good data set)

Test	No. of Cars	Test Mode	Pollutant	Conventional Correlation Coefficient	Canonical Variable	Canonical Correlation Coefficient
Federal Short Cycle	39		HC	0.87	1	0.89
			CO	0.81	2	0.80
			NO_x	0.62	3	0.61
NY/NJ Composite	39		HC	0.92	1	0.92
			CO	0.77	2	0.82
			NO_x	0.61	3	0.61
Key Mode (Laboratory)	40	High speed	HC	0.74	1	0.96
			CO	0.23[a]	2	0.86
			NO_x	0.79	3	0.65
		Low speed	HC	0.70		--
			CO	0.38		--
			NO_x	0.16[a]		--
		Idle	HC	0.94		--
			CO	0.04[a]		--
			NO_x	0.24[a]		--
Key Mode (Garage)	40	High speed	HC	0.73	1	0.94
			CO	0.37	2	0.85
		Low speed	HC	0.73	3	0.65
			CO	0.21[a]		--
		Idle	HC	0.88		--
			CO	0.52		--
Federal Three-Mode (Laboratory)	31	High speed	HC	0.77	1	0.98
			CO	0.16[a]	2	0.93
			NO_x	0.83	3	0.55
		Low speed	HC	0.74		--
			CO	0.25[a]		--
			NO_x	0.02[a]		--
		Idle	HC	0.78		--
			CO	0.52		--
			NO_x	0.08[a]		--
Federal Three-Mode (Garage)	40	High speed	HC	0.76	1	0.90
			CO	0.24[a]	2	0.84
		Low speed	HC	0.73	3	0.58
			CO	0.21[a]		--
		Idle	HC	0.78		--
			CO	0.52		--
2500 rpm Unloaded (Laboratory)	40		HC	0.47	1	0.63
			CO	0.30[a]	2	0.49
			NO_x	0.23[a]	3	0.21[a]
2500 rpm Unloaded (Garage)	40		HC	0.50	1	0.58
			CO	0.14[a]	2	0.38
			NO_x	0.20[a]	3	0.26[a]

[a]Not significantly different from 0 at the 95% confidence level.

physical interpretation of the canonical variables is illusive for these tests. The canonical correlation coefficients for the unloaded test indicate the inferior correlation properties of this type procedure. With the exception of the unloaded test, the canonical correlation coefficients are significantly different from zero; i.e., the tests are correlated to some degree.

4.1.4 Summary of Preliminary Analysis Results

The HC and CO observations are generally more variable than the NO_x readings, as indicated by the dispersion results for the FTP (see Table 4-2). The test-to-test variation (α) can be quite high and, hence, repeatability of the test procedures can be poor.

Canonical variables may offer some advantages in further analysis. However, their interpretation is difficult, and in a first analysis the original variables seem appropriate.

A model of the distribution properties of the test data appears most likely to be log-normal. This type of model appears appropriate for predicting a contingency table for the total vehicle population.

4.2 PRINCIPAL STATISTICAL ANALYSIS TECHNIQUES AND RESULTS

The statistical procedures utilized consist of two complementing classes: correlation analysis and contingency table analysis. Correlation analysis addresses the direct relatability of the ST with the FTP. Correlation analysis is an important aid in identifying STs that have acute deficiencies. Contingency table analysis approaches the question of relatability from the viewpoint of the possible tradeoffs between impact on air quality and cost to the public (both direct and indirect). It is an important tool to aid in policy formulation and cost-benefit analysis. The following sections briefly define each such analysis technique and summarize its associated results.

4.2.1 Correlation Analysis

4.2.1.1 Conventional Method

A conventional correlation analysis includes the calculation of the sample correlation coefficient r, and an α-percent confidence interval for the population correlation coefficient ρ, on paired observations. Letting (x_i, y_i) i = 1, ----, N denote the observations, r is defined by

$$r = \frac{\sum_{i=1}^{N} (x_i - M_x)(y_i - M_y)}{S_x S_y}$$

where M_x, S_x, and M_y, S_y are the mean and standard deviation of the observations x_i and y_i, respectively. An α-percent confidence interval is given by (r-, r+), where the probability that the interval covers ρ is $\alpha/100$. For the 95 percent interval used in this study

$$r\pm = \tanh\left(z \pm \frac{1.96}{\sqrt{N - 3}}\right)$$

where $z = 1/2 \ln\left(\frac{1+r}{1-r}\right)$, (Fisher's Z statistic, Ref. 4-4).

The sample correlation coefficient is used as the prime quantitative measure of relatability. The closer r is to 1, the better the relation. A lack of relationship is indicated by $r = 0$. Negative r indicates an inverse relation between the observations, i.e., if one observation is high, the other is low, and vice versa. The confidence interval is viewed as reflecting the sensitivity of the calculations to the data. The wider the interval, the less predictable is the correlation coefficient and, hence, the relatability.

A scattergram is also an important device for assessing direct relatability. A scattergram is merely a two-dimension plot of the data pairs (x_i, y_i). This provides for visual examination of the data, which is crucial in any relatability study. A sample scattergram and the associated statistics are shown in Figure 4-1. Here HC on the Federal Short Cycle is plotted versus the HC on the FTP for the CEV fleet. The number of cases (N) is 39. The sample correlation coefficient (COR) is 0.872, while the 95 percent interval is (0.768, 0.931). The regression line of "y" on "x" (ST on the FTP) is produced by drawing a straight line between the two points marked Y on the right and left borders of the plot. This line represents a least squares fit of the data (as measured in the y direction). Similar scattergrams for each ST and each emission constituent (HC, CO, NO_x) were examined in the course of the study.

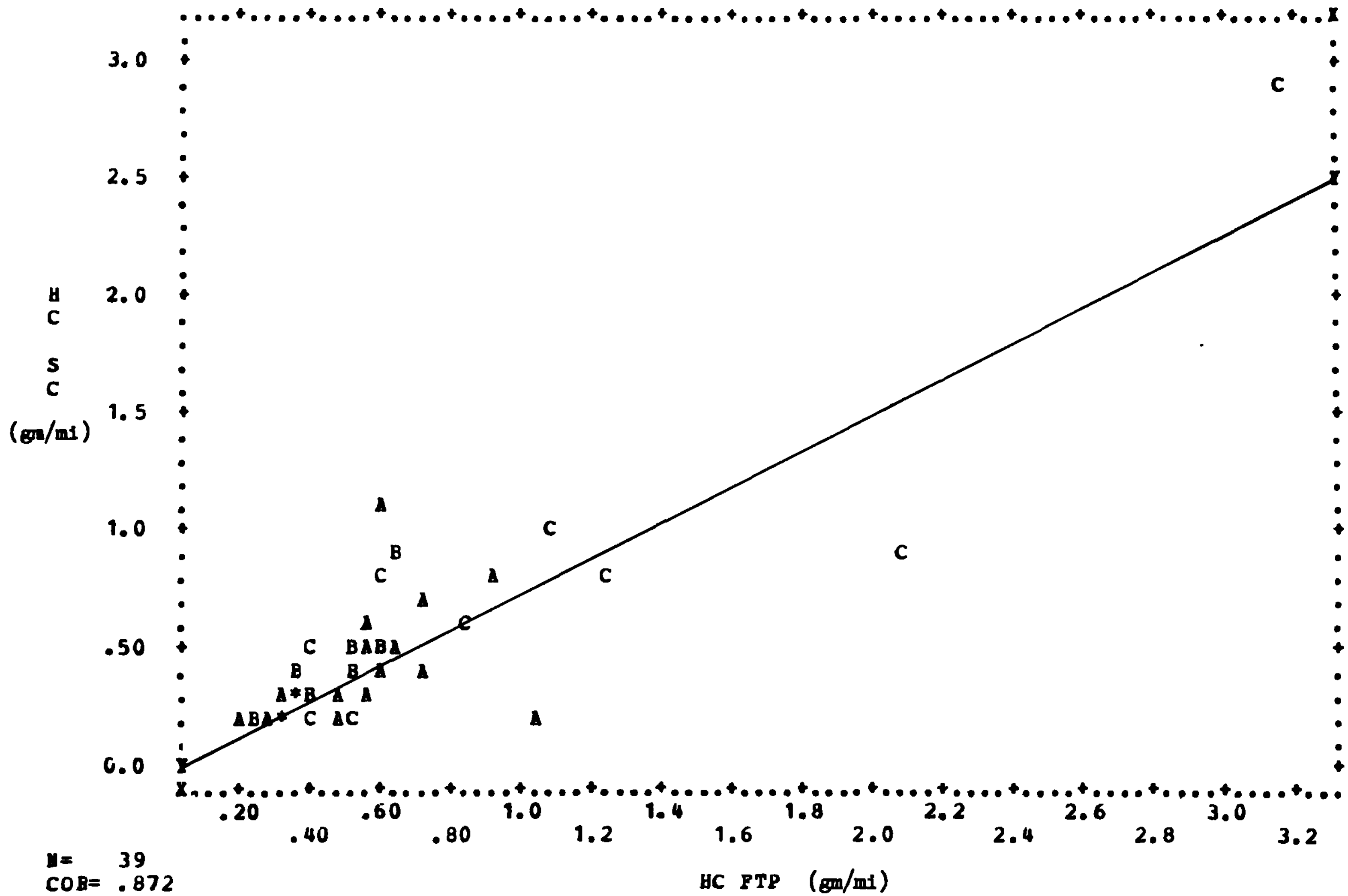
Since the data included replications on some cars, the data were organized into the following structure for conventional correlation analysis:

a. First Good Data

This data set contains the observations of the first FTP and ST, both of which are valid.

b. Second Good Data

This data set contains the second pair of FTP and ST observations, both of which are valid.



N= 39
COR= .872
95% INTERVAL: (0.768, 0.931)

	MEAN	ST.DEV.	REGRESSION LINE	RES.MS.
X	.64338	.53578	X= .99967*Y+ .13485	.07045
Y	.50870	.46756	Y= .76129*X+ .01891	.05365

Figure 4-1. Correlation Analysis Scattergram; CEV Fleet; Federal Short Cycle HC vs FTP HC

c. <u>Average Data</u>

This data set contains the average of the FTP and ST observations on each car (for the Federal Short Cycle and NY/NJ Composite only).

For each ST a correlation analysis was performed on first good data, second good data, and average data where appropriate. The following sections briefly summarize the significant results.

4.2.1.1.1 FTP Composite Emissions vs Individual FTP Bags

To gather insight on correlatable STs, the correlations between the FTP composite emissions and the individual FTP bag data were examined. The composite values were computed in the standard manner. The bag data were computed in grams of each pollutant per bag. Additionally, the sum of the bag 2 and bag 3 constituents were computed and the correlation coefficient with the composite data calculated. The analysis was conducted on both first and second good data.

Table 4-4 shows the FTP intra-correlations for like constituents. Additionally, cross correlation coefficients between dissimilar pollutants were computed (not shown). NO_x appeared to be uncorrelated with HC and CO. The cross correlation of HC and CO was typically 0.4 to 0.6. The results shown in Table 4-4 indicate that both cold (bag 1) and hot (bag 2, bag 3, bag 2 + 3) test procedures have a high correlation with the FTP composite. Thus, it may be possible to develop prototype STs using sections of the FTP.

4.2.1.1.2 ST vs FTP Composite Emissions

A summary of ST/FTP correlation coefficients is given in Table 4-5. For N = 40 or 39, a computed correlation coefficient greater than 0.35 indicates that the ST and FTP pollutants are statistically correlated at the 95 percent confidence level. For N = 25 or 26, this threshold is approximately 0.4.

Table 4-4. FTP Composite vs Bag Correlation Summary (CEV Fleet)

FTP Bag No.	Good Data Set[a]	Composite vs Bag Correlation Coefficient[b]		
		HC	CO	NO_x
1	First	0.90	0.96	0.95
	Second	0.91	0.93	0.91
2	First	0.94	0.90	0.87
	Second	0.99	0.81	0.79
3	First	0.84	0.86	0.95
	Second	0.97	0.87	0.97
2+3	First	0.98	0.95	0.99
	Second	0.99	0.90	0.98

[a] First good data contained 40 cars
Second good data contained 26 cars

[b] The correlations are statistically significant at the 95% confidence level.

4.2.1.2 Multiple Regression Analysis

A regression analysis evaluates the relationship between a dependent variable and one or more independent variables. This technique was used to predict the FTP results from three-mode volumetric observations. For example, the constants h_0, a_1, a_2, and a_3 in

$$HC_{FTP} = h_0 + a_1 HC_I + a_2 HC_{LO} + a_3 HC_{HI}$$

are determined so that the correlation between the predicted HC_{FTP} as given above and the observed HC_{FTP} is maximum. The procedure is stepwise in that an independent variable is added one at a time in order of their largest contribution to the correlation (Ref. 4-1). Hence the order of

Table 4-5. ST/FTP Correlation Summary (CEV Fleet)

Short Test	Good Data Set[(a)]	Test Mode	N[(b)]	"r"-ST/FTP Correlation[(c)] Coefficient		
				HC	CO	NO_x
Federal Short Cycle	First		39	0.87	0.81	0.62
	Second		25	0.91	0.42	0.47
	Average		39	0.93	0.83	0.53
NY/NJ Composite	First		39	0.92	0.77	0.61
	Second		25	0.92	0.71	0.51
	Average		40	0.95	0.68	0.61
Key Mode (Laboratory)	First	High	40	0.61	0.26*	0.79
		Low		0.53	0.39	0.20*
		Idle		0.92	0.54	0.27*
	Second	High	26	0.57	0.30*	0.86
		Low		0.53	0.31*	0.04*
		Idle		0.97	0.40	0.04*
Key Mode (Garage)	First	High	40	0.73	0.37	
		Low		0.73	0.21*	
		Idle		0.88	0.52	
	Second	High	26	0.51	0.08*	
		Low		0.39*	0.09*	
		Idle		0.32*	-0.03*	
Federal Three-Mode (Laboratory)	First	High	31	0.87	0.08*	0.89
		Low		0.79	0.22*	0.03*
		Idle		0.80	0.48	0.13*
	Second	High	26	0.68	0.20*	0.92
		Low		0.52	0.27*	-0.28*
		Idle		0.94	0.34*	0.08*
Federal Three-Mode (Garage)	First	High	40	0.76	0.24*	
		Low		0.73	0.21*	
		Idle		0.78	0.52	
	Second	High	26	0.69	0.12*	
		Low		0.42	0.03*	
		Idle		0.62	0.39*	
2500 rpm (Laboratory)	First		40	0.47	0.30*	0.23*
	Second		26	0.37*	0.25*	0.23*
2500 rpm (Garage)	First		40	0.50	0.14*	
	Second		26	0.36*	0.25*	

(a) First Good Data: This data set contains the observations of the first FTP and ST, both of which are valid.

Second Good Data: This data set contains the second pair of FTP and ST observations, both of which are valid.

Average Data: This data set contains the average of the FTP and ST observations on each car (for the Federal Short Cycle and NY/NJ Composite only).

(b) Number of cars in data set

(c) The correlation is statistically significant at the 95% confidence level except when indicated by an asterisk.

inclusion indicates the mode's relative importance. The ordering of the modes varies depending on the ST and pollutant under study.

A multiple regression analysis was performed for the three-mode volumetric tests on first good data. The purpose of this analysis was to empirically determine the linear combinations of the three-mode readings that have maximum correlation with the FTP. The linear combinations are composed of like constituents. Thus, each linear combination can be considered as a weighted observation on HC, CO, and NO_x. The results are shown in Table 4-6, along with the maximum correlation coefficient using only a single reading on each constitutent. As can be seen from Table 4-6, the weighted combination correlation coefficients are not significantly higher than the correlation coefficient of the best single reading.

Table 4-6. ST/FTP Correlations for Weighted Mode Tests (CEV Fleet) (first good data only)

Short Test	N[a]	Weighted Correlation Coefficient[b]			Best Single-Mode[c] Correlation Coefficient[b]		
		HC	CO	NO_x	HC	CO	NO_x
Key Mode							
Laboratory	40	0.93	0.55	0.83	0.92 (I)	0.54 (I)	0.79 (H)
Garage	40	0.91	0.58		0.88 (I)	0.52 (I)	
Federal Three-Mode							
Laboratory	31	0.91	0.48	0.90	0.87 (H)	0.48 (I)	0.89 (H)
Garage	40	0.81	0.53		0.78 (I)	0.52 (I)	

[a] Number of cars in data set

[b] Correlations are statistically significant at the 95% confidence level

[c] H - high speed mode
I = idle mode

4.2.1.3 Correlation Sensitivity Analysis

As previously mentioned, the sensitivity of the analysis to the data used can be assessed by using the confidence interval. To dramatize this sensitivity, a worst case approach was examined by deleting selected extreme data points from the existing data. Recalculation of the correlation coefficient was performed to illustrate the variability due to the sample. This was done in a sequential manner for the Federal Short Cycle. A summary of the analysis results for the Federal Short Cycle-FTP correlations is shown in Table 4-7. A review of Table 4-7 values indicates that the results are extremely sensitive to a small percentage of the data points.

4.2.1.4 Discussion of Selected Correlation Analysis Results

4.2.1.4.1 Shortcomings of the Correlation Coefficient

The main usage of the correlation coefficient is as an indicator of direct relatability between ST and FTP. In this respect it has a number of deficiencies. The computed correlation coefficient is sensitive to the location

Table 4-7. Correlation Coefficients for Selected Car Deletions; Federal Short Cycle vs FTP (CEV Fleet)

Number of Cars Deleted	Correlation Coefficient[a]		
	HC	CO	NO_x
0	0.872	0.810	0.621
1	0.657	0.673	0.690
2	0.656	0.639	0.633
3	--	--	0.823
4	--	--	0.755

[a] Significant at the 95% confidence level

of a small percentage of the data, as shown in Table 4-7. It is a summary statistic in that all the information contained in the data is compressed into a single number (this is alleviated to some degree by examination of the scattergrams).

It is difficult to infer air quality impact from correlation statistics except in the broadest sense, and a tradeoff analysis is virtually impossible based solely on correlation coefficients.

4.2.1.4.2 Mode Tests vs Bag Tests

On the basis of HC and CO correlation, the bag tests (Federal Short Cycle and NY/NJ Composite) are preferable to the mode- or volumetric-type ST. The volumetric STs, in general, show deficiencies in tracking CO. The high-speed modes, however, have superior NO_x correlation.

4.2.1.4.3 Laboratory Analyzers vs Garage Instruments

The largest difference between the correlation results of the two measurement techniques occurs on the second good data sets. There is a greater variation in the correlation estimates of first good data and second good data for the garage analyzer than for the laboratory analyzer, as shown in Table 4-5. This is most likely due to the combination of low CO values for the CEV fleet, small sample size, and less accurate instrumentation.

The most striking difference between laboratory and garage data is for HC on the Federal Three-Mode. The laboratory measurements indicate the best mode to be high speed, while the garage readings indicate the idle mode as superior. This is inconsistent with the results for HC on the Clayton Key Mode, and may be attributed to the difference in the sample sizes of the Federal Three-Mode and the Clayton Key Mode tests.

CO correlation deficiency is common to both measurement techniques. Due to the low concentration of CO being emitted, this may be a measurements problem, in general, rather than a deficiency in ST structure.

4.2.1.4.4 ST Correlation Ratings

The following qualitative rating scale was used to rate the ST:

Rating	Description
(U) Unacceptable	Constituent is uncorrelated at 95% confidence level
(P) Poor	Constituent is correlated at the 95% confidence level, but with correlation less than 0.6
(F) Fair	Correlation between 0.6 and 0.7
(G) Good	Correlation between 0.7 and 0.9
(E) Excellent	Correlation between 0.9 and 1.0

For rating the three-mode volumetric ST, the mode with the highest rating was used. Table 4-8 shows the ratings of the ST on each pollutant on this basis.

In general, the STs have less difficulty tracking HC than CO and NO_x. Excluding the Unloaded 2500 rpm ST (which has either "P" or "U" ratings for all three pollutants), the bag-type and modal STs all have "G" to "E" ratings for HC. In the case of CO, the bag-type STs have "G" ratings, whereas the modal STs are rated in the "P" category. This situation is reversed in the case of NO_x, where the modal STs have "G" ratings and the bag-type STs are rated "F" to "P". Hence, the choices among the STs for CO and NO_x implementation may be more limited than for HC.

4.2.2 Contingency Table Analysis

The contingency table analysis is used to establish the ST pass-fail levels for each pollutant. The contingency table is defined in Table 4-9, along with its associated parameters. A pictorial demonstration of its application to a given data set is shown in Figure 4-2. This figure shows that, for a given data set, ST cut-points must be established in order to compute the elements of the contingency table. Four basic approaches for cut-point determination were considered, which are described as follows.

Table 4-8. ST Correlation Ratings

Short Test	Rating		
	HC	CO	NO_x
Federal Short Cycle	G	G	F
NY/NJ Composite	E	G	P
Key Mode			
Laboratory	E (I)[a]	P (I)	G (H)
Garage	G (I)	P (I)	
Federal Three-Mode			
Laboratory	G (H)	P (I)	G (H)
Garage	G (I)	P (I)	
2500 rpm Unloaded			
Laboratory	P	U	U
Garage	P	U	

[a] I = idle mode, H = high speed mode

Table 4-9. Contingency Table

		True = FTP		
		Pass	Fail	Total
Predicted = Short Test	Pass	a	b	a + b
	Fail	c	d	c + d
	Total	a + c	b + d	n = a + b + c + d

a = number of correctly passed vehicles (PP)

b = number of error of omission (E_o)

c = number of error of commission (E_c)

d = number of correctly failed vehicles (FF)

Sensitivity = a/(a + c)

Specificity = b/(b + d)

False positive error = b/(a + b)

False negative error = c/(c + d)

$$\text{Correlation index} = \frac{ad - bc}{[(a + b)(a + c)(b + d)(c + d)]^{1/2}}$$

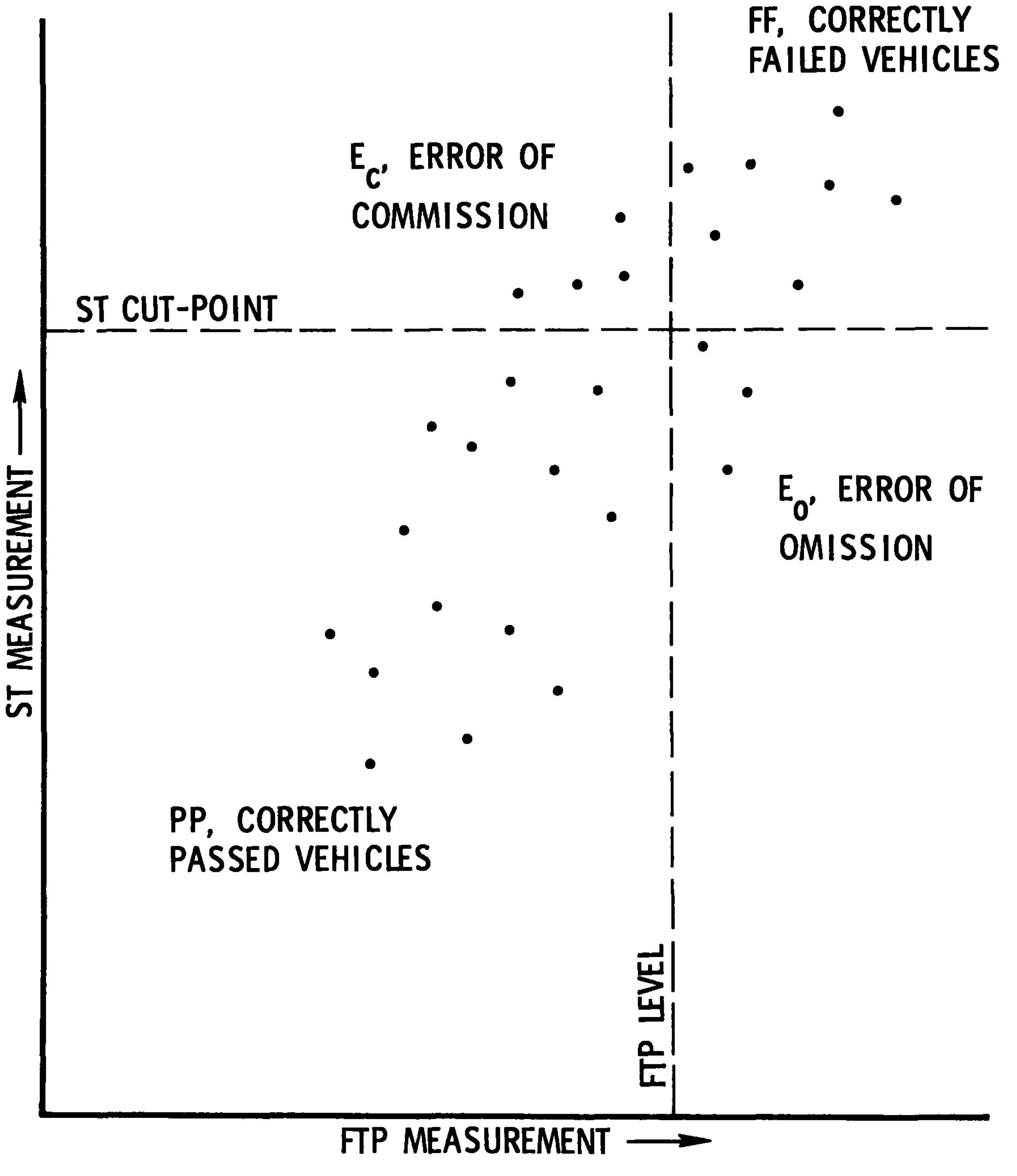


Figure 4-2. Contingency Table Representation

4.2.2.1 Analysis Methods Examined

4.2.2.1.1 Maximum Correlation Method

In this method, the ST cut-point is selected so that the correlation index (as defined in Table 4-9) is maximized. This is an impartial procedure for finding the STs that give the best correlation with the FTP under the terms of the contingency table. Figure 4-3 graphically illustrates the procedure. This method provides for no policy decision.

4.2.2.1.2 Bounded Errors of Commission Method

The ST cut-points are selected to minimize the errors of omission while holding the errors of commission below a specified level. This method permits a direct answer to the question, "For a given permissible level of errors of commission, what level of errors of omission must be accepted, and with what impact on air quality (inferred from the number of FF vehicles)?" This method is pictorially demonstrated in Figure 4-4. The policy decision is the maximum allowable errors of commission.

4.2.2.1.3 Weighted Errors Method

The strategy used in this method is, as indicated by Figure 4-5, to minimize a linear combination of the errors of commission and the errors of omission. The linear combination represents cost to the public, where the weights indicate the relative importance of the two types of costs: those incurred by manufacturers, versus those due to deterioration of air quality. Air quality impact is inferred from the level of FF vehicles. The policy decision is the cost structure; that is, the specification of the weights.

4.2.2.1.4 Percent Rejection Method

The ST cut-points are determined so that a specified percentage of the population is failed by the ST. This is shown graphically in Figure 4-6. The policy decision is the percentage to be rejected by the ST.

PARAMETRIC TECHNIQUE

USE LINEAR REGRESSION AS A MODEL:

$X_2 - AX_1 + B$

SOLVE FOR C_2 WHEN $X_1 = C_1$

I.E.,

$C_2 = AC_1 + B$

DATA ANALYTIC TECHNIQUE

SELECT SHORT TEST LEVEL SUCH THAT THE TABLE CORRELATION IS MAXIMUM

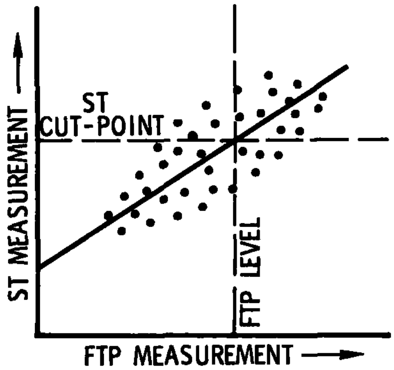


Figure 4-3. Maximum Correlation Method

MINIMIZE E_0 SUBJECT TO $E_C \leq \gamma\%$

PARAMETRIC TECHNIQUE ONLY. USE BIVARIATE NORMAL PROBABILITY MODEL

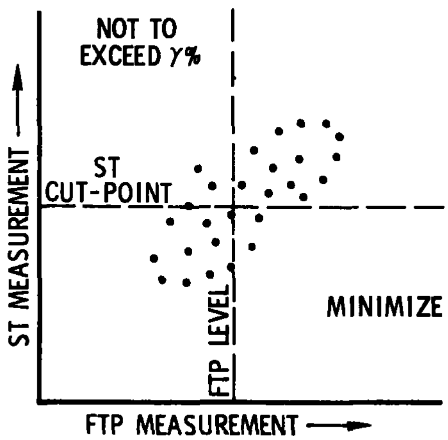


Figure 4-4. Bounded Errors of Commission Method

MINIMIZE $\alpha E_C + \beta E_0$

PARAMETRIC TECHNIQUE

USE BIVARIATE NORMAL PROBABILITY MODEL

DATA ANALYTIC TECHNIQUE

SELECT THE SHORT TEST LEVEL SO THAT $\alpha E_C + \beta E_0$ IS MINIMUM

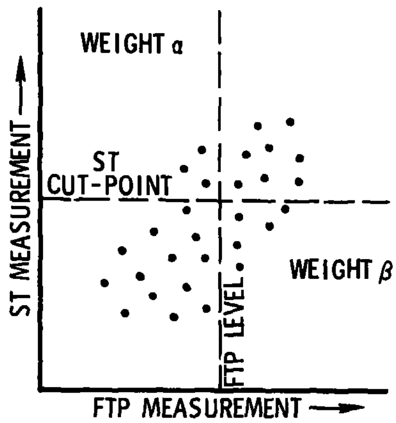


Figure 4-5. Weighted Errors Method

REJECT α% OF THE SAMPLE

PARAMETRIC TECHNIQUE

USE BIVARIATE NORMAL PROBABILITY MODEL

DATA ANALYTIC TECHNIQUE

SELECT THE SHORT TEST LEVEL UNTIL SPECIFIED PERCENT IS REJECTED

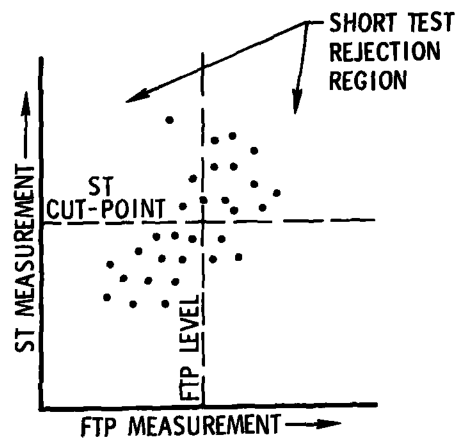


Figure 4-6. Percent Rejection Method

4.2.2.2 Procedural Techniques Utilized

The techniques used to compute the ST cut-points and the contingency table entries are classified as data analytic and parametric. The data analytic technique uses the data directly without resort to a model. The parametric procedure uses a model of the data.

4.2.2.2.1 Data Analytic Technique

The cut-point for each pollutant is determined individually. For each ST cut-point, the table entries are calculated by counting the number of data points in each of the appropriate regions indicated in Figure 4-2. Each ST cut-point is then iteratively varied until the objective of the particular strategy is achieved. This set of ST cut-points is then taken as the solution to the strategy under study.

This procedure was not applied to the method of bounded errors of commission. The bound typically ranged from 5 percent to 0.1 percent. In terms of actual counts, this range is 2.0 to 0.04 cars for the CEV fleet. The results would thus be sensitive to a very small portion of the data.

4.2.2.2.2 Parametric Technique

The data are first modeled by using a bivariate normal distribution as shown in Figure 4-7. Thus the correlation coefficient, mean values, and standard deviations are computed from the data and substituted into the model. The ST cut-points are then determined by using the model. Figure 4-8 indicates the pertinent probability calculations for predicting the table entries. The predicted table entries are shown in Figure 4-9. Figure 4-10 shows the equations to be solved to determine the ST cut-points.

After the ST cut-points have been determined, the contingency table results are calculated using both the actual data points and the model of the data.

BIVARIATE NORMAL DISTRIBUTION

$$D(X_1, X_2) = \frac{e^{-\left\{\frac{1}{2(1-\rho^2)}\left[\left(\frac{X_1-\mu_1}{\sigma_1}\right)^2 - 2\rho\left(\frac{X_1-\mu_1}{\sigma_1}\right)\left(\frac{X_2-\mu_2}{\sigma_2}\right) + \left(\frac{X_2-\mu_2}{\sigma_2}\right)^2\right]\right\}}}{2\pi\sigma_1\sigma_2\sqrt{1-\rho^2}}$$

WHERE μ_1, μ_2 = POPULATION MEANS

σ_1, σ_2 = POPULATION STANDARD DEVIATIONS

ρ = CORRELATION COEFFICIENT

X_1 = FTP MEASUREMENT

X_2 = ST MEASUREMENT

Figure 4-7. Parametric Model

PROBABILITY OF ERROR OF COMMISSION

$$Pr\{X_1 \le C_1, X_2 > C_2\} = \int_{-\infty}^{C_1}\int_{C_2}^{\infty} D(X_1, X_2)\, dX_1 dX_2$$

PROBABILITY OF ERROR OF OMISSION

$$Pr\{X_1 > C_1, X_2 \le C_2\} = \int_{C_1}^{+\infty}\int_{-\infty}^{C_2} D(X_1, X_2)\, dX_1 dX_2$$

PROBABILITY OF CORRECT FAILURES

$$Pr\{X_1 > C_1, X_2 > C_2\} = \int_{C_1}^{+\infty}\int_{C_2}^{+\infty} D(X_1, X_2)\, dX_1 dX_2$$

WHERE C_1 = CRITICAL FTP LEVEL

C_2 = CRITICAL ST LEVEL

Figure 4-8. Probability Equations

EXPECTED ERRORS OF COMMISSION AND OMISSION

E_c = N x [PROBABILITY OF ERROR OF COMMISION]

E_0 = N x [PROBABILITY OF ERROR OF OMISSION]

EXPECTED CORRECT FAILURES

FF = N x [PROBABILITY OF CORRECT FAILURE]

$PP = N - FF - E_c - E_0$

WHERE N = NUMBER OF CARS USED

Figure 4-9. Expected Values

SOLVE FOR C_2

PERCENT REJECTION

$$\alpha = Pr \left\{X_2 > C_2\right\} = \int_{-\infty}^{+\infty} \int_{C_2}^{+\infty} D(X_1, X_2)\, dX_1, dX_2$$

WEIGHTED ERRORS

$$\min_{C_2} (\alpha E_c + \beta E_0)\ ;\ \alpha + \beta = 1$$

BOUNDED ERRORS OF COMMISSION:

$$\min_{C_2} (E_0)\ ;\ E_0 \leq \gamma$$

Figure 4-10. Equations for Parametric Techniques

4.2.2.3 Selected Analysis Methods

Only two of the above four cut-point-level selection strategies were investigated in any detail: the maximum correlation method and the bounded errors of commission method. The maximum correlation method was chosen for comparison with the previous correlation analysis. The information contained in an analysis under the other two strategies is identical for varying policy decisions. That is, as the policy is varied under each strategy, the resulting loci of E_c, E_o, and FF are identical. Hence, the bounded errors of commission method was chosen for its particular relevance to the cost to manufacturers and air quality impact.

As the emissions standard to which the CEV fleet was designed is uncertain, four sets of FTP cut-points were used in the analyses. These are specified in Table 4-10.

Table 4-10. Assumed FTP Levels (CEV Fleet)

Level	Emission Level, gm/mi		
	HC	CO	NO_x
I	0.41	3.4	3.1
II	0.60	5.0	3.1
III	0.75	7.0	3.1
IV	0.90	9.0	3.1

4.2.2.4 Maximum Correlation Analysis Results

The problem of presenting the results can best be seen while observing relationships of E_c, E_o, and FF to changing FTP level. For example, Figure 4-11 illustrates a typical plot for HC, using the data analytic calculation technique. Similarly, Figure 4-12 shows the same results using the parametric calculational technique on the actual data points only, while Figure 4-13 shows the results as predicted from a model of the data. Trends are clearly more visible in the predicted population results. Although these trends are an intrinsic component of the model, the actual magnitudes and rates of change of the trends are due to the data.

A summary of the results of the maximum correlation analysis for the predicted population of the CEV fleet is shown in Tables 4-11 through 4-14. For N = 40 or 39, a computed table correlation coefficient greater in magnitude than 0.31 indicates that the ST and FTP pollutants are statistically correlated at the 95 percent confidence level. For N = 31, this threshold is 0.35. Figures 4-13 to 4-24 depict the relationship of E_c, E_o, and FF to changing FTP level for HC and CO on the predicted population basis. Figure 4-25 shows the variation of E_o and E_c for NO_x.

The correlation index of the contingency table, as defined in Table 4-9, is substantially different than the computed correlation coefficients of Sec. 4.2.1. Although the relative ranking of the ST may be similar to that of Table 4-8, experience has shown that contingency table correlation index is an unreliable indicator of relatability. For example, consider the extreme case where E_o = 0.0, E_c = 0.0, and FF = 0.01%. In this case the correlation index will be 1.0; however, 99.99% of the data are in the correctly passed group, and the correlation index tells nothing about 99.99% of the data. This example also indicates that the correlation index is a function of the ST and FTP cut-points. Although this is desirable for policy analysis, tradeoffs are best inferred by directly observing the pertinent quantities.

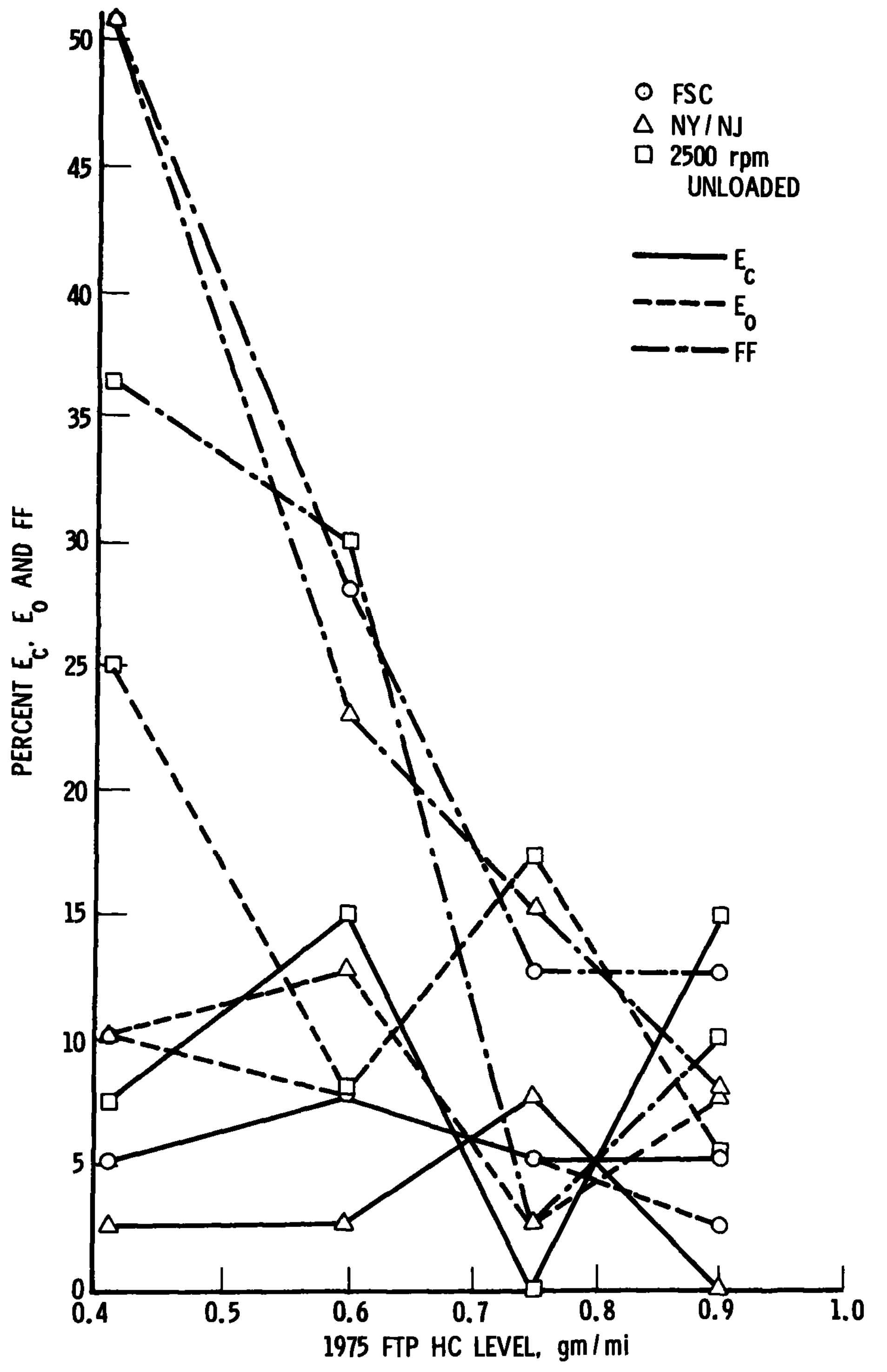


Figure 4-11. Variation of E_C, E_O, and FF with HC FTP Level; Maximum Correlation Method; Data Analytic Technique; CEV Fleet

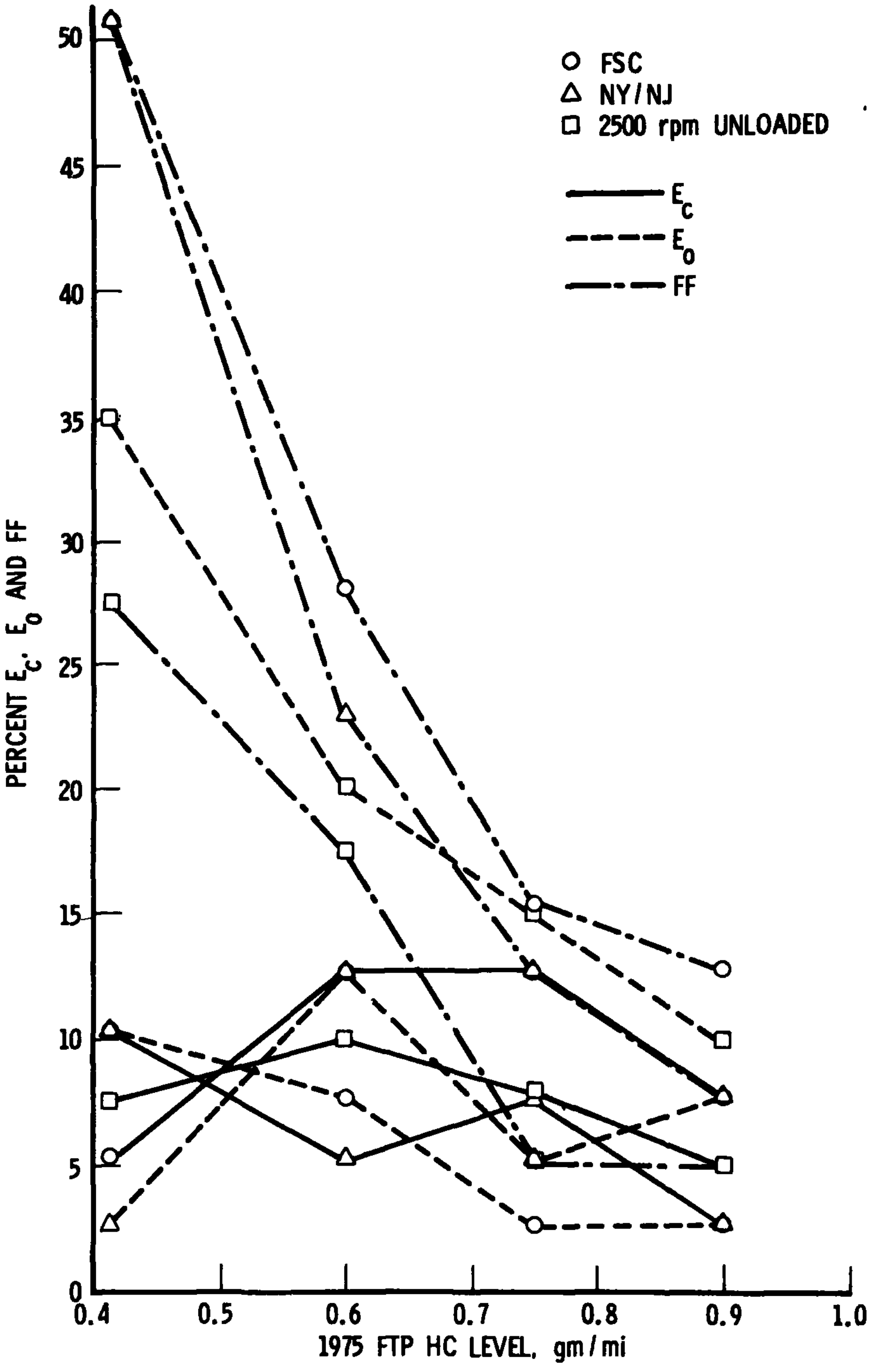


Figure 4-12. Variation of E_c, E_o, and FF with HC FTP Level; Maximum Correlation Method; Parametric Technique; CEV Fleet

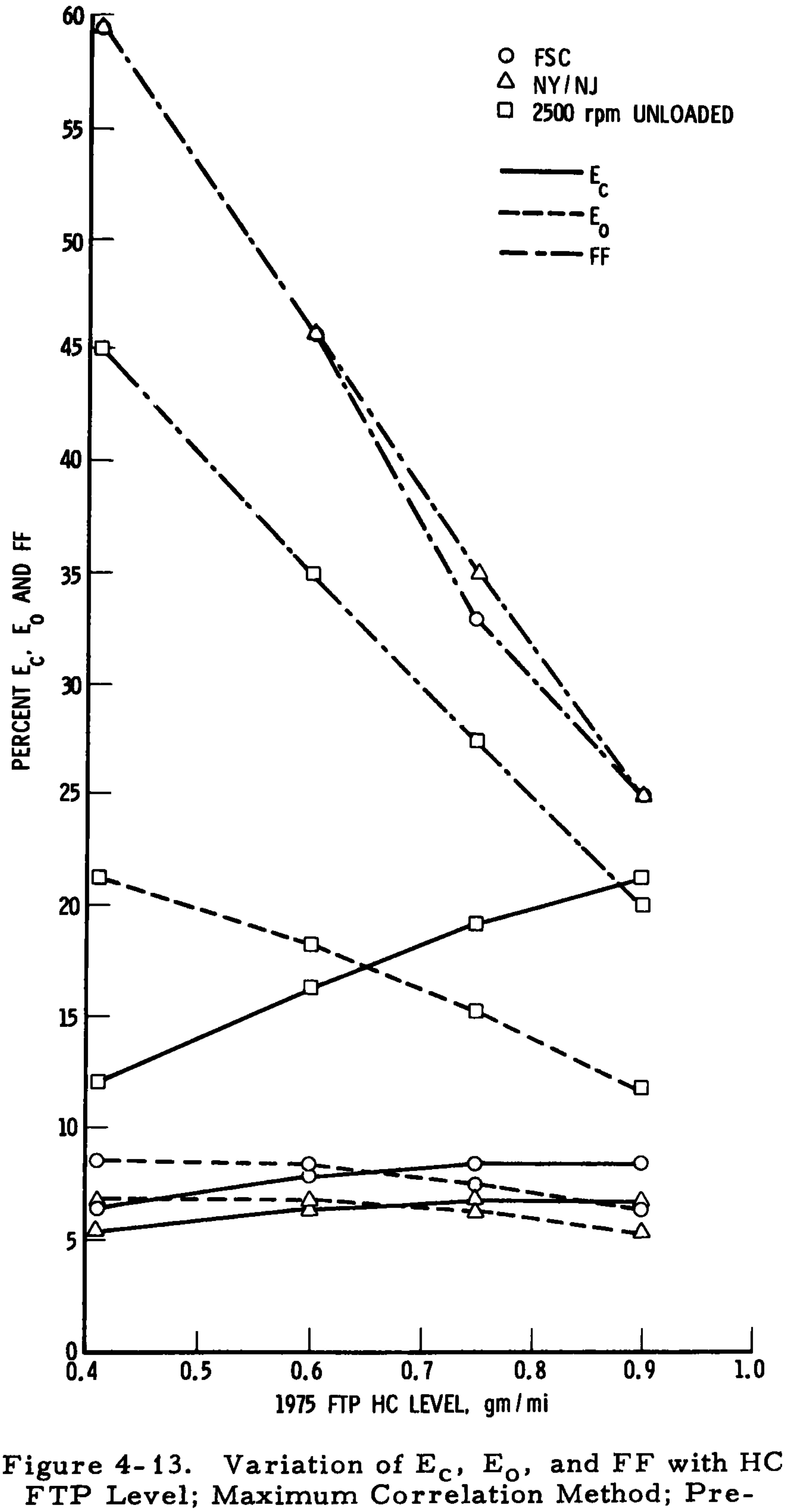


Figure 4-13. Variation of E_c, E_o, and FF with HC FTP Level; Maximum Correlation Method; Predicted Population Technique; CEV Fleet

Table 4-11. Maximum Correlation Summary, FTP Level I (CEV Fleet)

Short Test	N	Test Mode	Pollutant	% E_c	% E_a	% FF	Table Correlation Index[a]
Federal Short Cycle	39		HC	6.49	8.53	58.3	0.667
			CO	10.8	8.23	28.0	0.596
			NO_x	16.3	5.26	9.71	0.372
NY/NJ Composite	39		HC	5.38	6.72	60.1	0.730
			CO	12.0	8.94	27.3	0.556
			NO_x	16.7	5.32	9.65	0.363
Key Mode (Laboratory)	40	High	HC	10.6	17.2	50.1	0.405
			CO	23.1	18.5	25.3	0.166*
			NO_x	10.0	4.40	11.2	0.532
		Low	HC	11.5	19.4	47.8	0.344
			CO	20.4	16.6	27.2	0.257
			NO_x	33.6	7.13	8.43	0.105*
		Idle	HC	5.21	6.51	60.8	0.737
			CO	17.2	14.4	29.4	0.363
			NO_x	30.4	6.9	8.69	0.147
Key Mode (Garage)	40	High	HC	8.95	13.4	53.9	0.514
			CO	20.9	16.8	26.6	0.242
		Low	HC	9.05	13.6	53.6	0.507
			CO	24.2	18.9	24.4	0.136
		Idle	HC	6.30	8.27	58.9	0.675
			CO	17.8	14.6	28.7	0.346
Federal Three-Mode (Laboratory)	31	High	HC	6.29	8.60	60.3	0.661
			CO	23.9	23.5	26.0	0.050*
			NO_x	5.49	2.72	8.96	0.644
		Low	HC	7.70	11.39	57.5	0.571
			CO	21.7	21.3	28.2	0.140*
			NO_x	42.9	5.78	5.90	0.012*
		Idle	HC	7.64	11.3	57.6	0.575
			CO	17.1	16.9	32.7	0.321
			NO_x	37.8	5.55	6.14	0.063
Federal Three-Mode (Garage)	40	High	HC	8.47	12.4	54.9	0.544
			CO	23.7	18.6	24.7	0.151
		Low	HC	8.99	13.4	53.7	0.511
			CO	24.1	18.9	24.4	0.137*
		Idle	HC	8.17	11.7	55.5	0.563
			CO	17.9	14.7	28.7	0.344
2500 rpm Unloaded	50		HC	12.2	21.1	46.1	0.300
			CO	22.4	17.7	25.6	0.194*
			NO_x	32.4	6.67	8.09	0.121*
2500 rpm Unloaded (Garage)	40		HC	11.8	20.2	46.9	0.323
			CO	25.6	19.9	23.5	0.089*

(a) The correlation is statistically significant at the 95% confidence level except where indicated by an asterisk

Table 4-12. Maximum Correlation Summary, FTP Level II (CEV Fleet)

Short Test	N	Test Mode	Pollutant	% E_c	% E_o	% FF	Table Correlation Index[a]
Federal Short Cycle	39		HC	7.90	8.31	44.9	0.675
			CO	7.10	2.36	5.63.	0.510
NY/NJ Composite	39		HC	6.42	6.70	46.5	0.737
			CO	8.38	2.50	5.48	0.467
Key Mode (Laboratory)	40	High	HC	14.0	15.2	37.7	0.415
			CO	30.8	7.58	9.51	0.142*
		Low	HC	15.5	16.8	36.0	0.354
			CO	25.4	7.03	10.1	0.223*
		Idle	HC	6.28	6.50	46.3	0.744
			CO	19.6	6.35	10.7	0.321
Key Mode (Garage)	40	High	HC	11.4	12.3	41.1	0.523
			CO	26.2	7.01	9.80	0.209*
		Low	HC	11.6	12.5	40.9	0.519
			CO	32.7	7.64	9.18	0.116*
		Idle	HC	7.69	8.10	45.4	0.683
			CO	20.5	6.37	10.4	0.304*
Federal Three-Mode (Laboratory)	31	High	HC	7.73	8.56	47.8	0.670
			CO	35.6	11.3	12.2	0.46
		Low	HC	9.68	10.99	45.4	0.582
			CO	30.8	10.5	13.0	0.127*
		Idle	HC	9.60	10.9	45.4	0.585
			CO	21.8	8.89	14.6	0.297*
Federal Three-Mode (Garage)	40	High	HC	10.7	11.5	41.9	0.553
			CO	31.7	7.55	9.27	0.129*
		Low	HC	11.5	12.4	41.1	0.521
			CO	32.7	7.63	9.18	0.116*
		Idle	HC	10.3	11.1	42.4	0.572
			CO	20.5	6.38	10.4	0.302*
2500 rpm Unloaded (Laboratory)	40		HC	16.3	18.2	35.3	0.309
			CO	29.1	7.30	9.52	0.166*
2500 rpm Unloaded (Garage)	40		HC	15.8	17.5	35.9	0.332
			CO	35.7	7.90	8.91	0.075*

[a] The correlation is statistically significant at the 95% confidence level except where indicated by an asterisk

Table 4-13. Maximum Correlation Summary, FTP Level III (CEV Fleet)

Short Test	N	Test Mode	Pollutant	% E_c	% E_o	% FF	Table Correlation Index[a]
Federal Short Cycle	39		HC	8.49	7.50	34.6	0.673
			CO	1.16	0.11	0.21	0.312*
NY/NJ Composite	39		HC	6.79	6.14	36.0	0.736
			CO	1.57	0.12	0.21	0.267*
Key Mode (Laboratory)	40	High	HC	16.2	12.7	28.4	0.413
			CO	29.4	1.20	1.40	0.082*
		Low	HC	18.1	13.9	27.2	0.352
			CO	20.7	1.13	1.47	0.134*
		Idle	HC	6.61	5.91	35.12	0.742
			CO	6.98	13.1	1.54	0.207*
Key Mode (Garage)	40	High	HC	12.8	10.7	31.5	0.522
			CO	21.9	1.12	1.42	0.125*
		Low	HC	13.0	10.9	31.3	0.515
			CO	32.5	1.19	1.35	0.066*
		Idle	HC	8.26	7.33	34.9	0.682
			CO	14.1	1.05	1.49	0.193*
Federal Three-Mode (Laboratory)	31	High	HC	8.46	7.93	38.0	0.670
			CO	42.8	2.59	2.74	0.031*
		Low	HC	10.8	9.97	36.0	0.582
			CO	33.4	2.47	2.86	0.086*
		Idle	HC	10.7	9.89	36.1	0.586
			CO	18.7	2.19	3.14	0.214*
Federal Three-Mode (Garage)	40	High	HC	11.9	10.1	32.1	0.552
			CO	30.8	1.18	1.36	0.074*
		Low	HC	12.9	10.8	31.4	0.519
			CO	32.4	1.19	1.35	0.067*
		Idle	HC	11.4	9.71	32.5	0.570
			CO	14.2	1.05	1.49	0.192*
2500 rpm Unloaded (Laboratory)	40		HC	19.2	15.1	27.1	0.308
			CO	26.4	1.15	1.39	0.097*
2500 rpm Unloaded (Garage)	40		HC	18.5	14.6	27.6	0.330
			CO	37.9	1.22	1.32	0.043*

[a] The correlation is statistically significant at the 95% confidence level except where indicated by an asterisk

Table 4-14. Maximum Correlation Summary, FTP Level IV (CEV Fleet)

Short Test	N	Test Mode	Pollutant	% E_c	% E_o	% FF	Table Correlation Index[a]
Federal Short Cycle	39		HC	8.49	6.28	25.3	0.665
			CO	0.05	0.0	0.00	0.138*
NY/NJ Composite	39		HC	6.66	5.22	26.4	0.729
			CO	0.09	0.0	0.00	0.104*
Key Mode (Laboratory)	40	High	HC	17.4	9.85	20.2	0.401
			CO	22.3	0.08	0.09	0.030*
		Low	HC	19.7	10.7	19.4	0.341
			CO	12.3	0.08	0.09	0.053*
		Idle	HC	6.40	4.93	25.1	0.734
			CO	5.49	0.07	0.10	0.092*
Key Mode (Garage)	40	High	HC	13.4	8.69	22.9	0.512
			CO	13.5	0.07	0.09	0.048*
		Low	HC	13.6	8.79	22.8	0.505
			CO	26.5	0.08	0.08	0.024*
		Idle	HC	8.24	6.14	25.4	0.674
			CO	6.26	0.07	0.09	0.083*
Federal Three-Mode (Laboratory	31	High	HC	8.69	6.89	28.9	0.665
			CO	41.8	0.30	0.31	0.014*
		Low	HC	11.4	8.51	27.3	0.576
			CO	29.0	0.29	0.32	0.041*
		Idle	HC	11.2	8.44	27.4	0.580
			CO	11.0	0.26	0.35	0.113*
Federal Three-Mode (Garage)	40	High	HC	12.4	8.23	23.3	0.542
			CO	24.2	0.08	0.09	0.027*
		Low	HC	13.5	8.73	22.9	0.509
			CO	26.3	0.08	0.08	0.024*
		Idle	HC	11.7	7.94	23.6	0.561
			CO	6.32	0.07	0.09	0.083*
2500 rpm Unloaded (Laboratory)	40		HC	21.3	11.8	19.8	0.299*
			CO	18.7	0.08	0.09	0.036*
2500 rpm Unloaded (Garage)	40		HC	20.4	11.4	20.1	0.321
			CO	33.9	0.08	0.08	0.015*

(a)The correlation is statistically significant at the 95% confidence level except where indicated by an asterisk

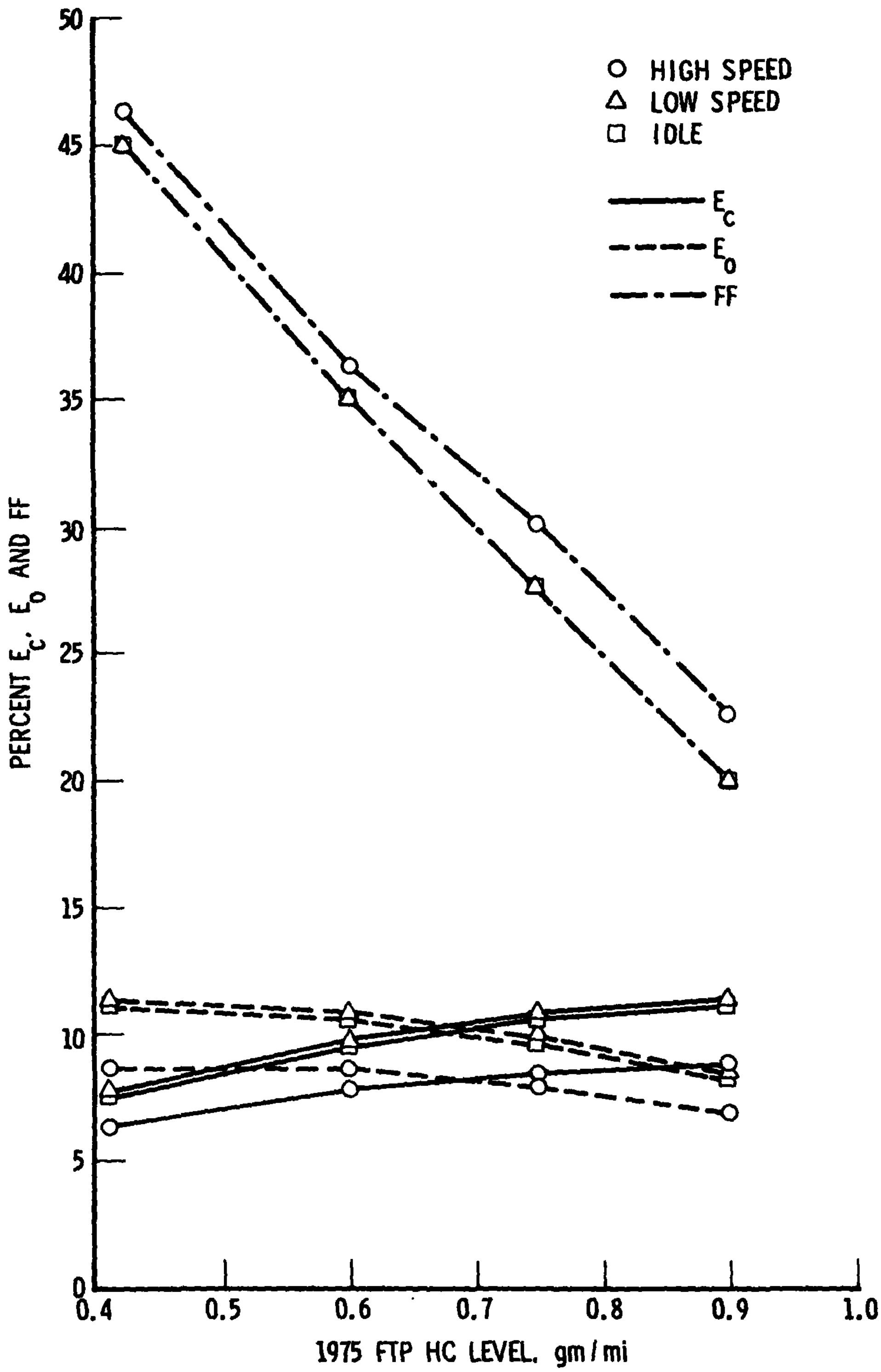


Figure 4-14. Variation of E_c, E_o, and FF with HC FTP Level; Federal Three-Mode Test; Maximum Correlation Method; Predicted Population of CEV Fleet

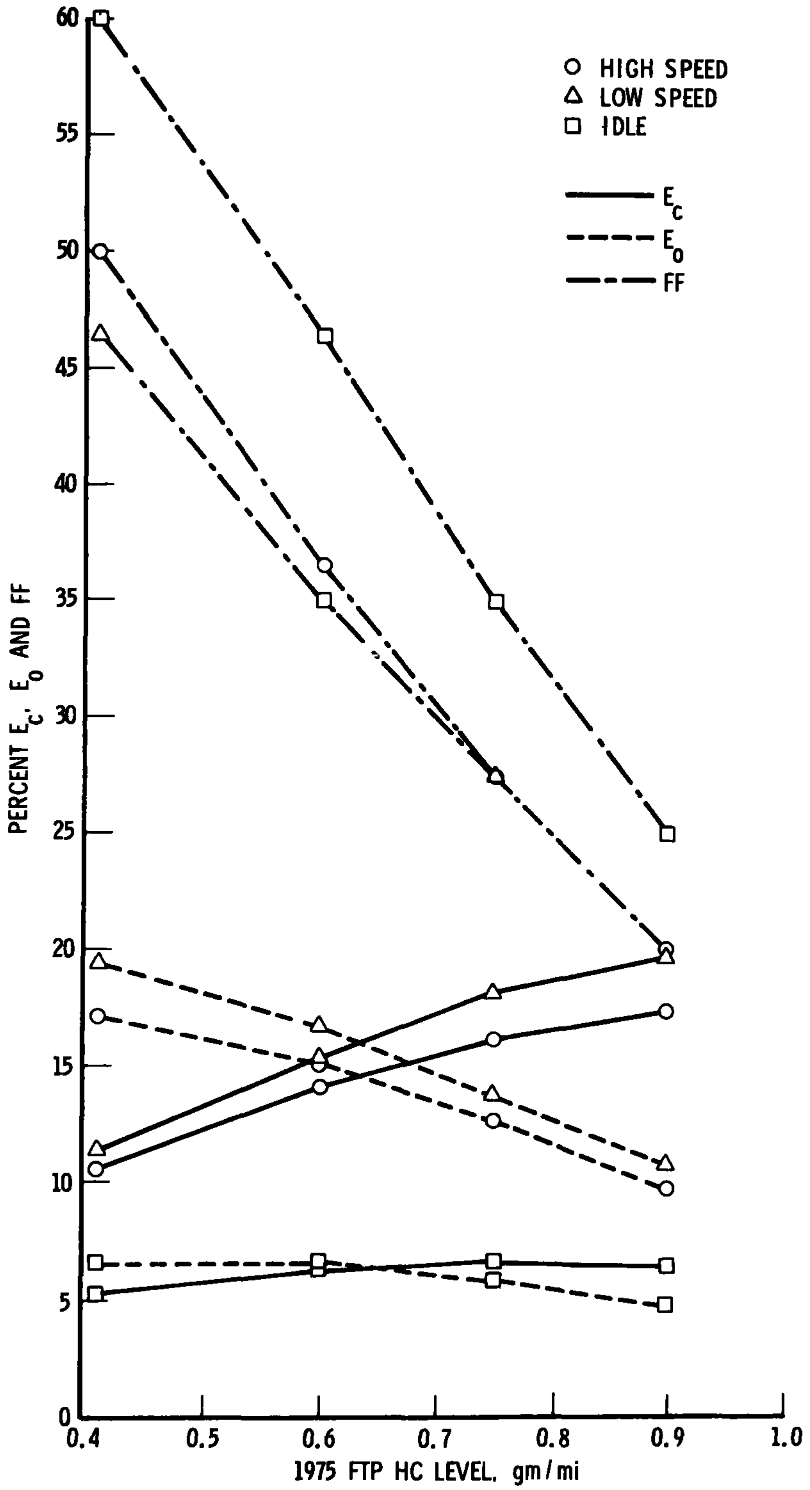


Figure 4-15. Variation of E_C, E_O, and FF with HC FTP Level; Key Mode Test; Maximum Correlation Method; Predicted Population of CEV Fleet

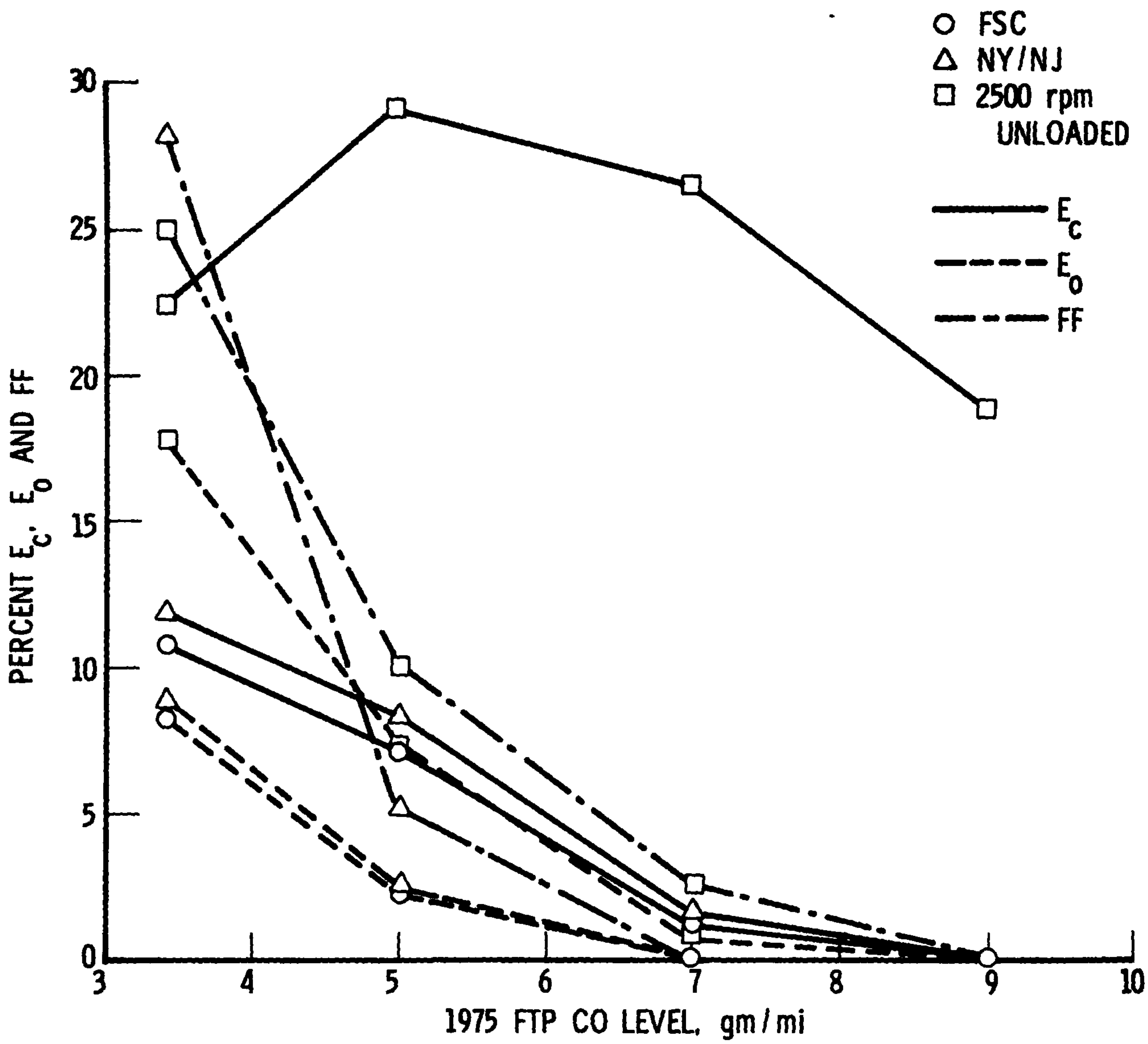


Figure 4-16. Variation of E_C, E_O, and FF with CO FTP Level; Maximum Correlation Method; Predicted Population of CEV Fleet

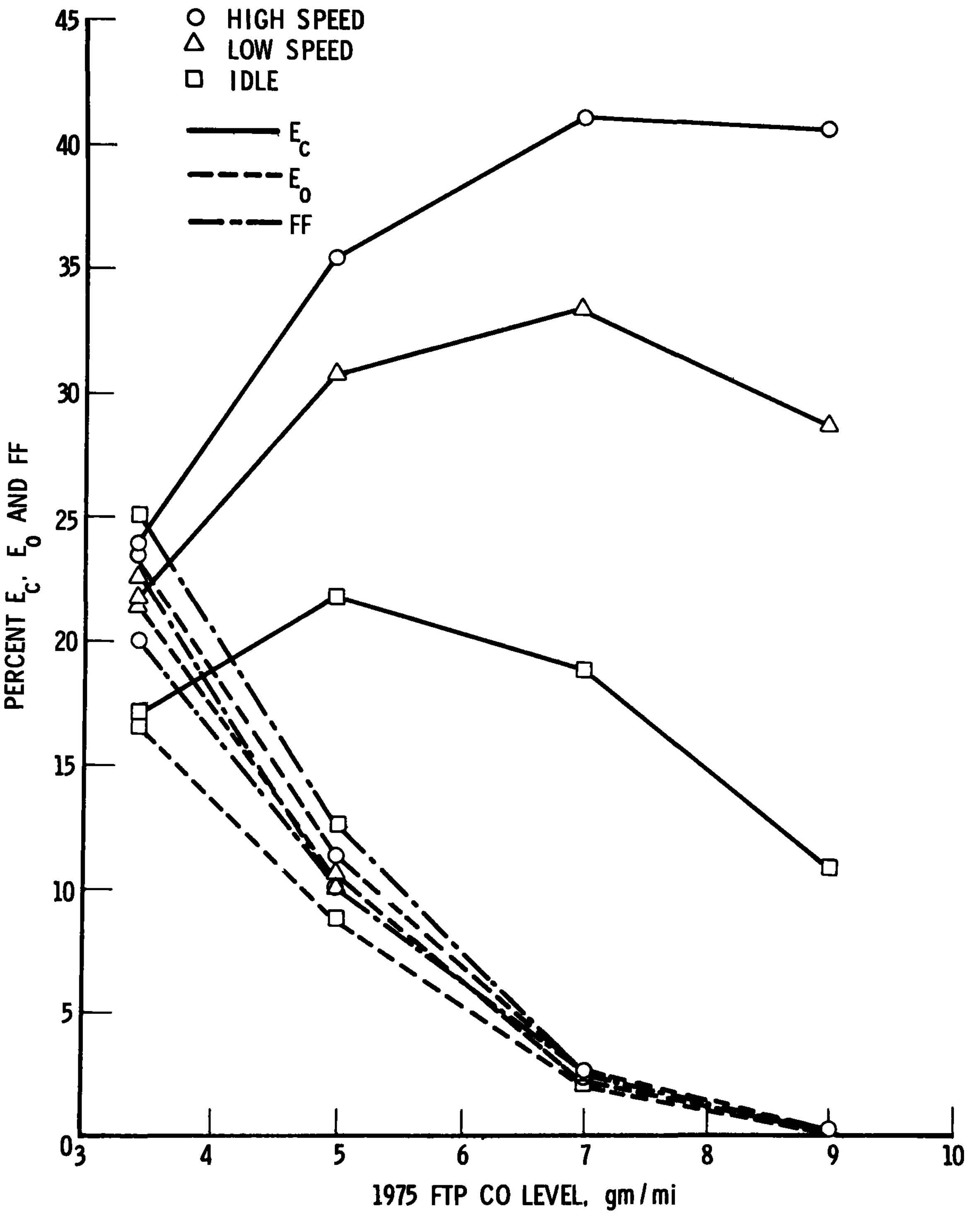


Figure 4-17. Variation of E_c, E_o, and FF with CO FTP Level; Federal Three-Mode Test; Maximum Correlation Method; Predicted Population of CEV Fleet

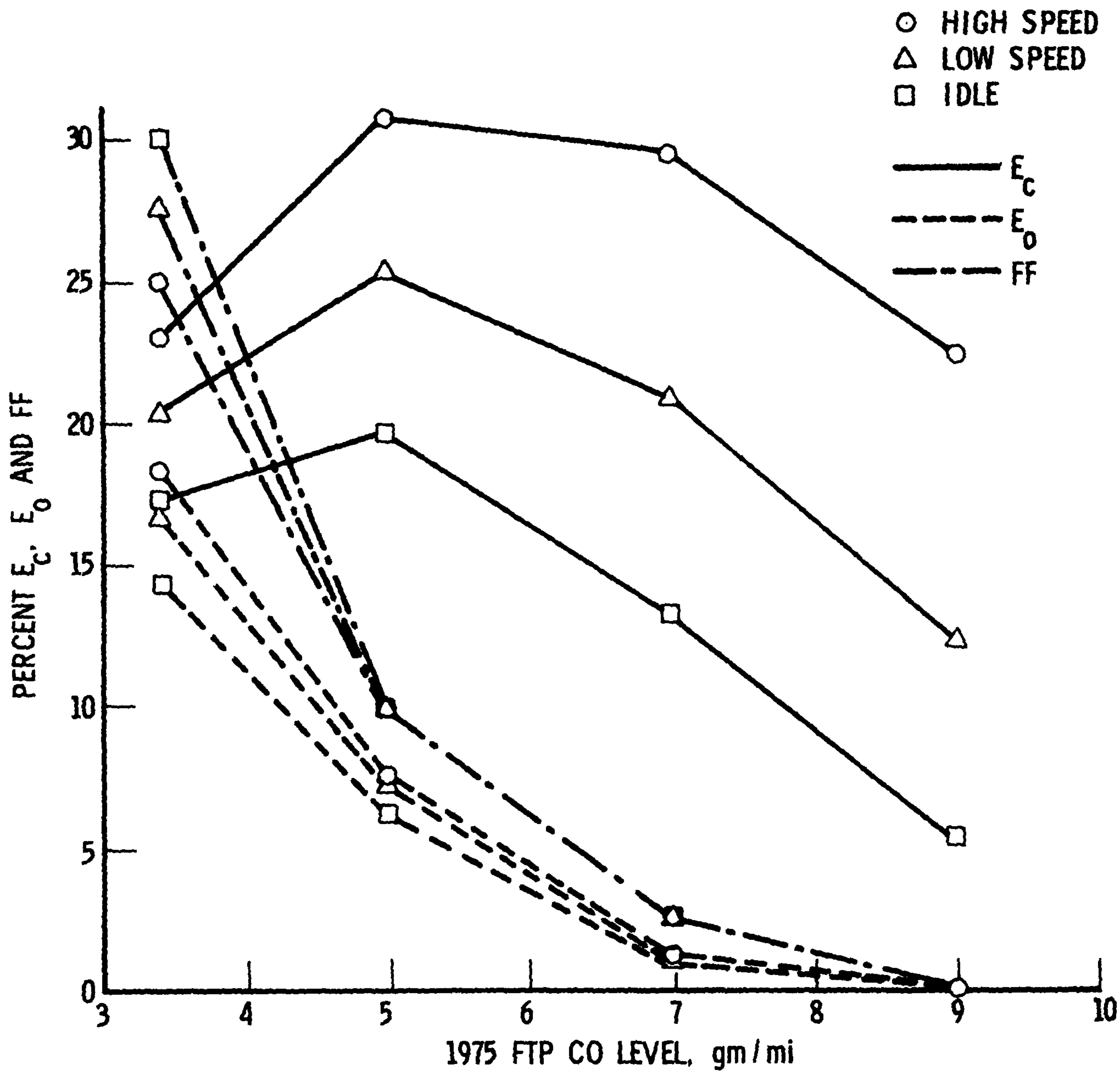


Figure 4-18. Variation of E_c, E_o, and FF with CO FTP Level; Key Mode Test; Maximum Correlation Method; Predicted Population of CEV Fleet

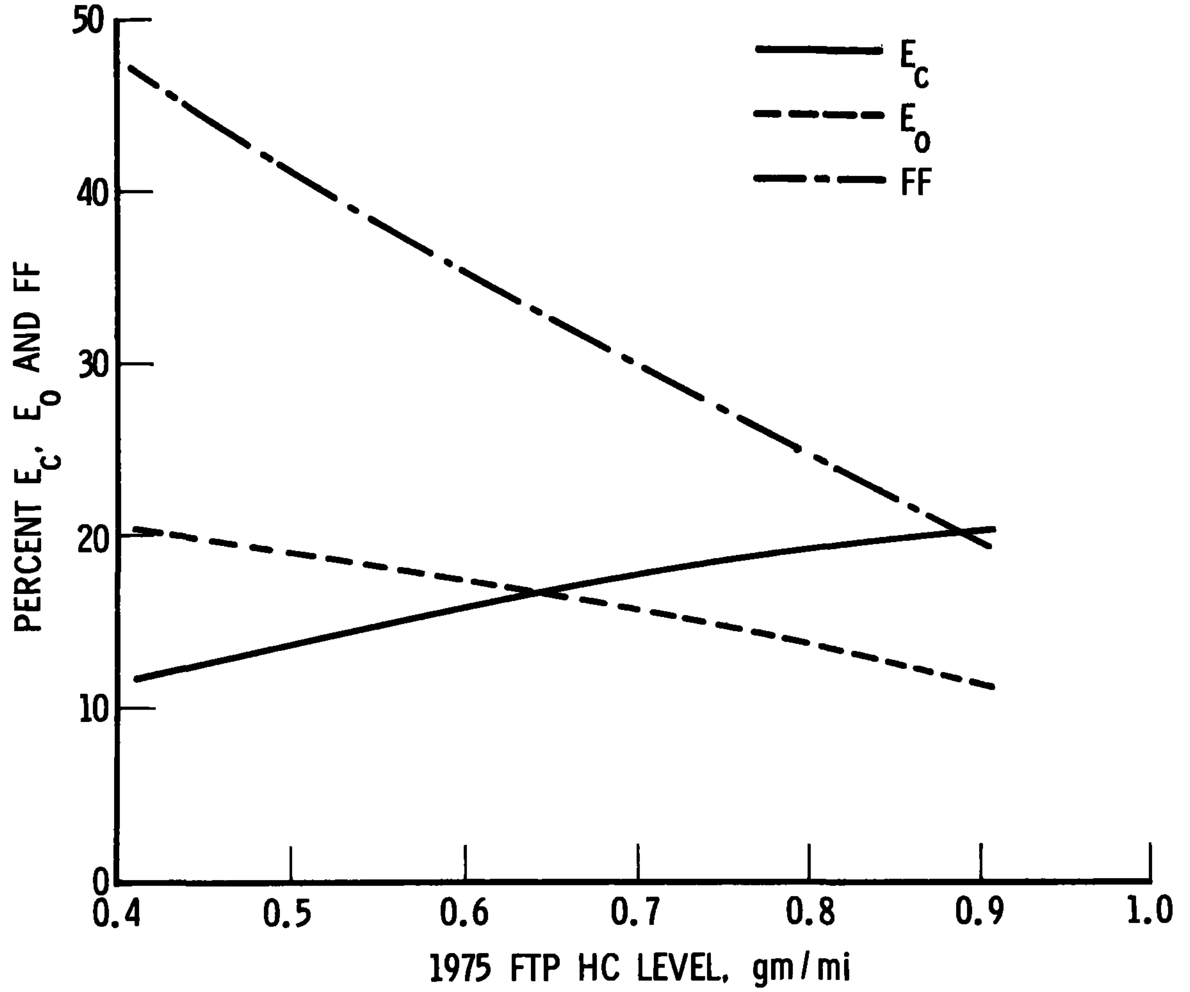


Figure 4-19. Variation of E_C, E_O, and FF with HC FTP Level; Unloaded 2500 rpm Test; Garage Instruments; Maximum Correlation Method; Predicted Population of CEV Fleet

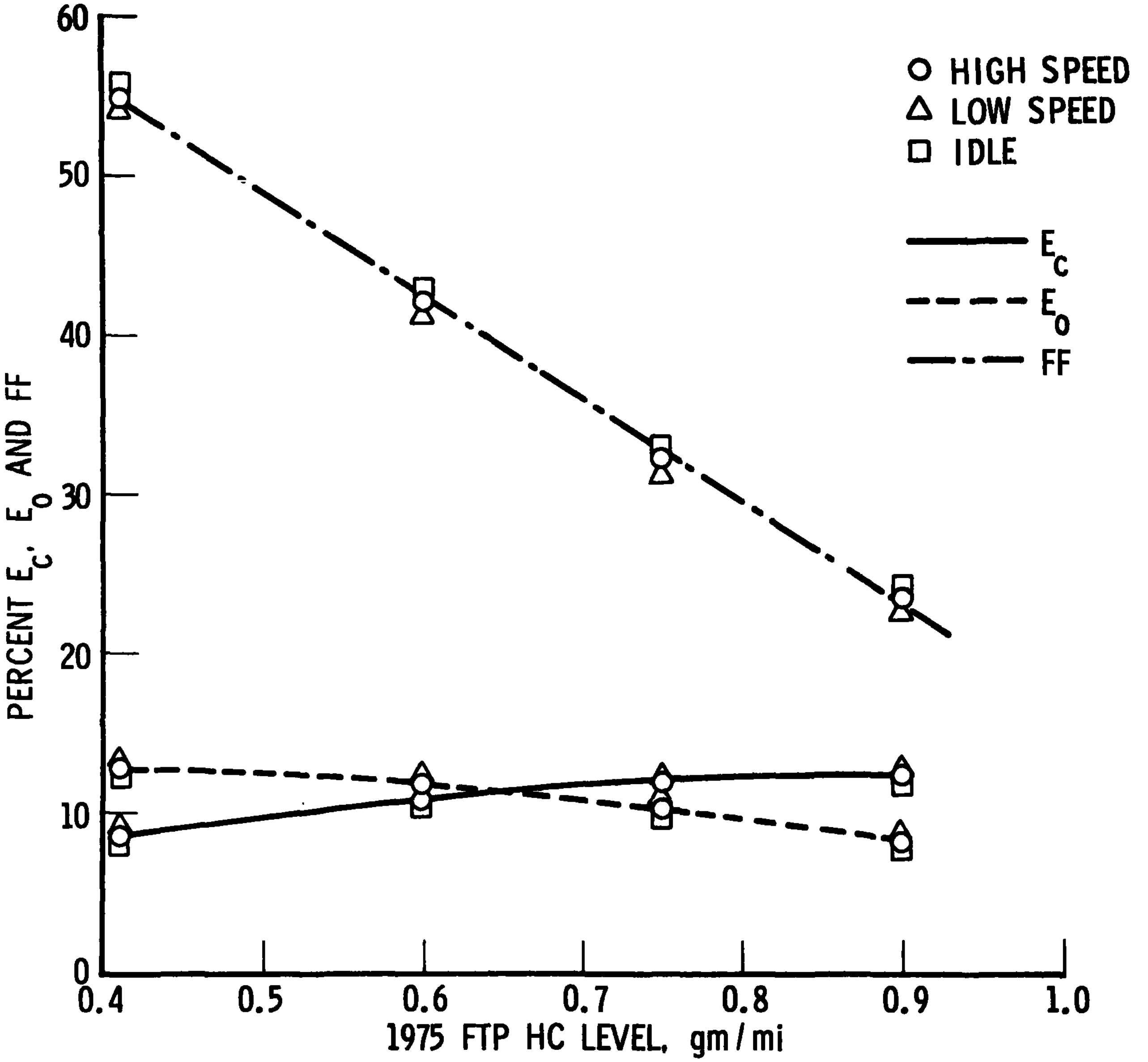


Figure 4-20. Variation of E_c, E_o, and FF with HC FTP Level; Federal Three-Mode Test; Garage Instruments; Maximum Correlation Method; Predicted Population of CEV Fleet

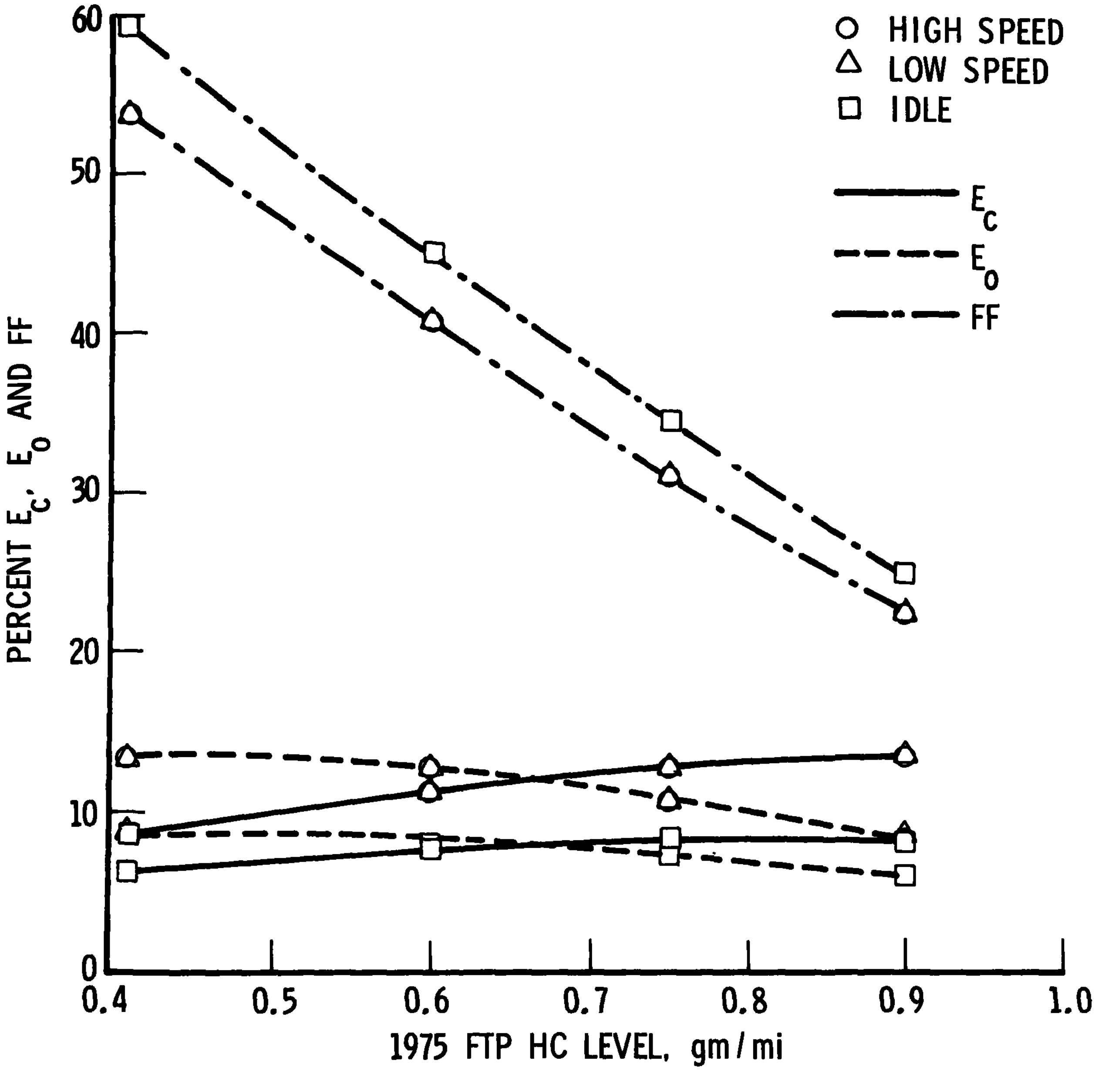


Figure 4-21. Variation of E_c, E_o, and FF with HC FTP Level; Key Mode Test; Garage Instruments; Maximum Correlation Method; Predicted Population of CEV Fleet

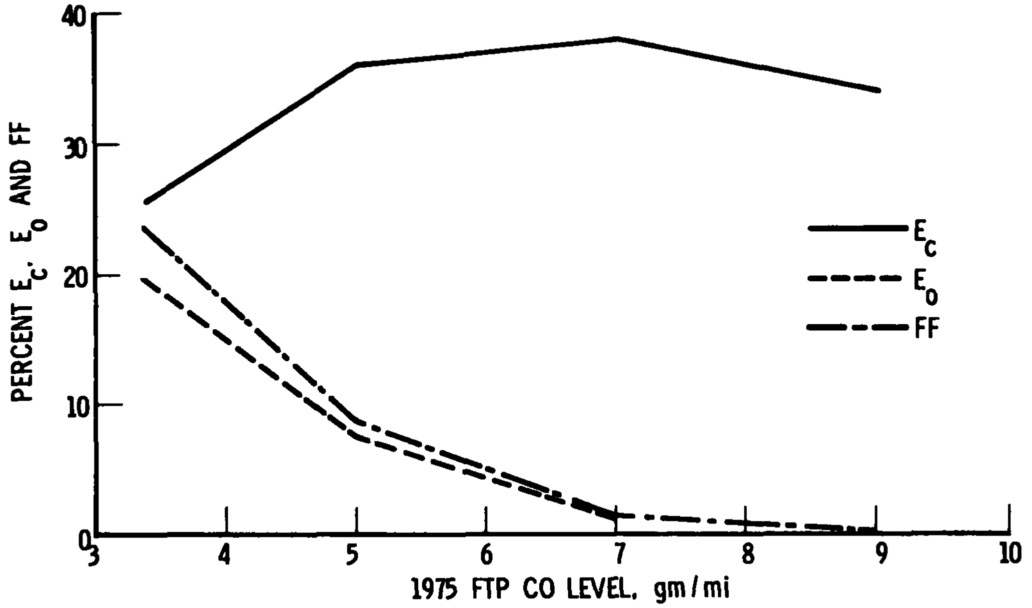


Figure 4-22. Variation of E_C, E_O, and FF with CO FTP Level; Unloaded 2500 rpm Test; Garage Instruments; Maximum Correlation Method; Predicted Population of CEV Fleet

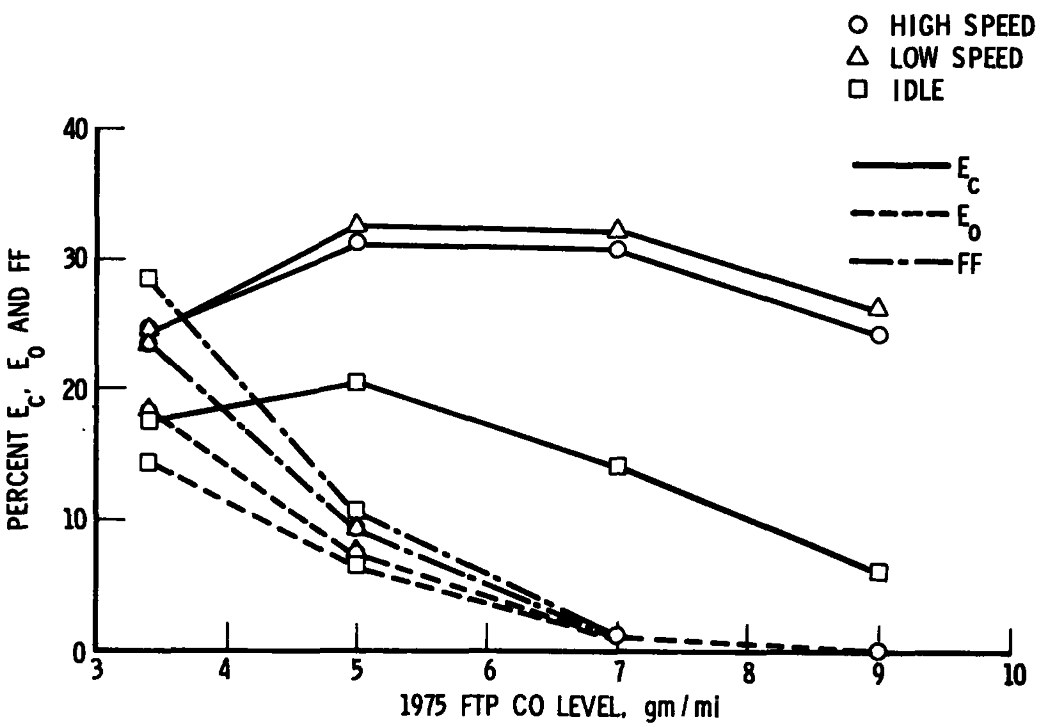


Figure 4-23. Variation of E_C, E_O, and FF with CO FTP Level; Federal Three-Mode Test; Garage Instruments; Maximum Correlation Method; Predicted Population of CEV Fleet

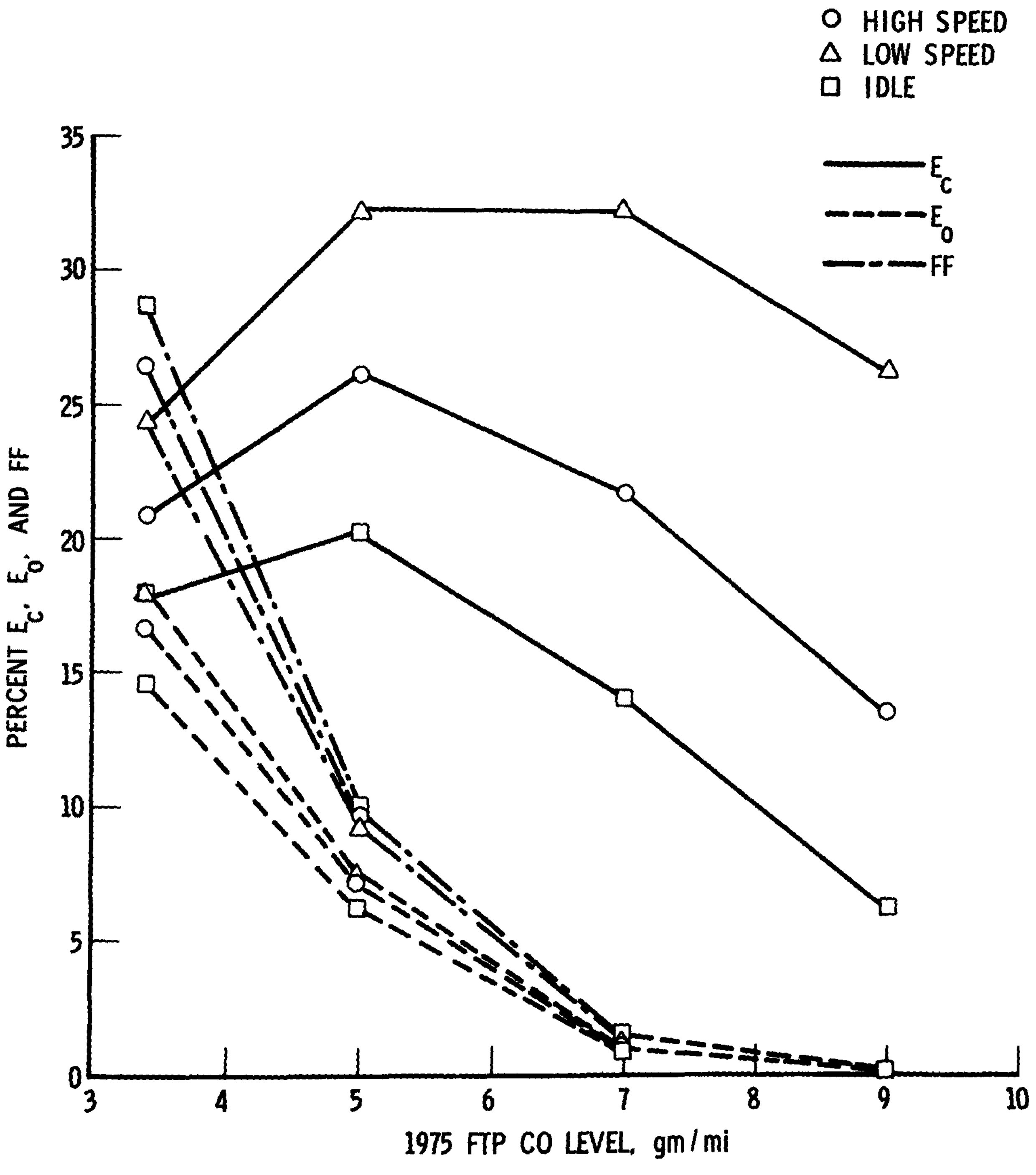


Figure 4-24. Variation of E_c, E_o, and FF with CO FTP Level; Key Mode Test; Garage Instruments; Maximum Correlation Method; Predicted Population of CEV Fleet

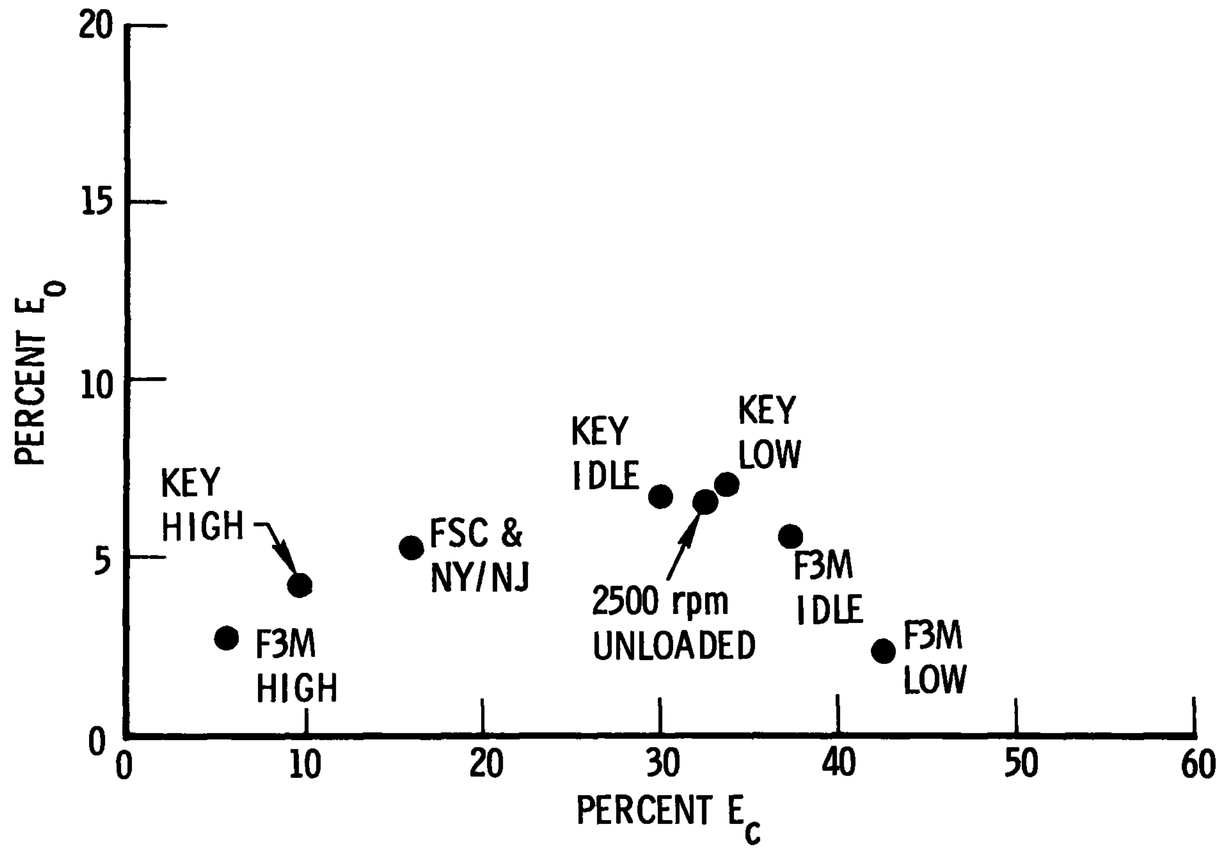


Figure 4-25. Variation of E_o and E_c at NO_x Level of 3.1 gm/mi; CEV Fleet; Maximum Correlation Method; Predicted Population of CEV Fleet

By examination of the values of E_c, E_o, and FF in Tables 4-11 through 4-14, the ST can be seen to follow the correlation ratings of Table 4-8. For example, on the Key Mode (Laboratory) for HC

	E_c	E_o	FF
High Speed:	10.6	17.2	50.1
Low Speed:	11.5	19.4	47.8
Idle:	5.21	6.51	60.8

As the idle mode has the highest percent FF and lowest percent E_c and E_o, it is a superior mode for HC. This is consistent with the ratings in Table 4-8.

The summary tables and the summary graphs do not clearly favor a single FTP level as a design level for the CEV fleet. However, the CO plots suggest that levels II, III, and IV are too high for CO as the percent FF dips below 15 percent on all tests.

The maximum correlation method does not admit a policy decision after the FTP level has been set. Thus its usefulness is restricted for purposes of tradeoff analysis.

4.2.2.5 Bounded Errors of Commission Analysis Results

4.2.2.5.1 Single-Constituent Tests

For the CEV fleet, the bound of errors of commission was varied from 5 percent to 1 percent in 1 percent increments, with the values 0.5 percent and 0.1 percent also included. An analysis was made for each of the FTP levels of Table 4-10. The results of the analysis are summarized in the following three sections. The data plotted are for the predicted CEV population. Since the exact FTP value is uncertain, only general observations can be made.

4.2.2.5.1.1 Hydrocarbon Emissions

The variation of E_o, E_c, and FF as a function of HC cut-point is displayed in Figures 4-26 through 4-35 for each ST examined, and for the range of HC FTP values selected in Table 4-10 (HC = 0.41 to 0.90). The figures correspond to the following ST/FTP level spectrum:

Short Test	FTP HC Level				Figure No.
	0.41	0.60	0.75	0.90	
Federal Short Cycle	X	X	X	X	4-26
NY/NJ Composite	X	X		X	4-27
Clayton Key Mode (Laboratory)	X			X	4-28
Clayton Key Mode (Garage)	X			X	4-29
Federal Three-Mode (Laboratory)	X				4-30
Federal Three-Mode (Laboratory)				X	4-31
Federal Three-Mode (Garage)	X				4-32
Federal Three-Mode (Garage)				X	4-33
2500 rpm Unloaded (Laboratory)	X	X	X	X	4-34
2500 rpm Unloaded (Garage)	X			X	4-35

The graphical displays indicate the general nature of the tradeoff available for policy formulation. Reducing the errors of commission (E_c) increases the errors of omission (E_o) and decreases the correct failures (FF). To illustrate specific values and trends among the STs, Tables 4-15 and 4-16

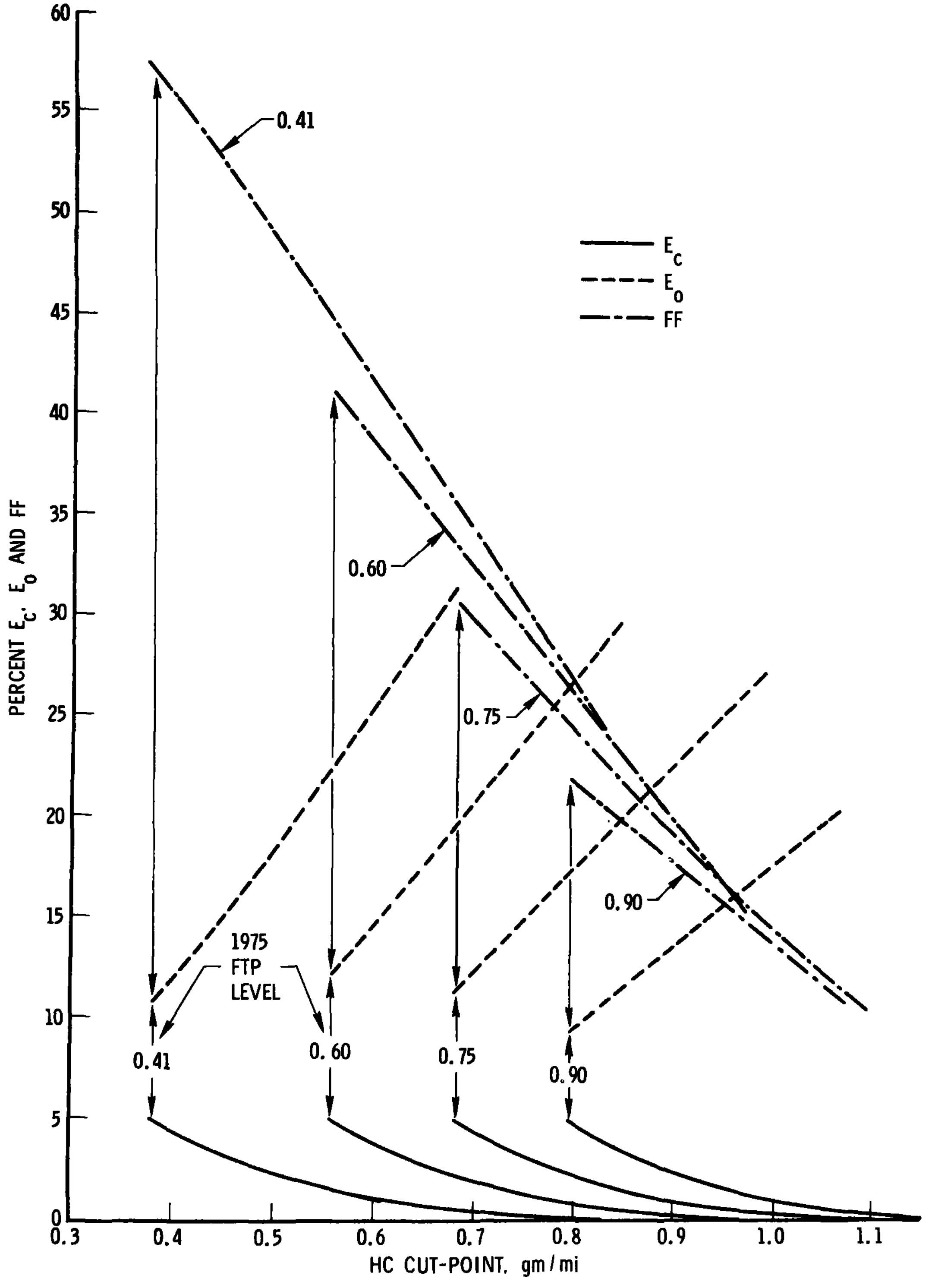


Figure 4-26. Variation of E_C, E_O, and FF with HC Cut-Point; CEV Fleet; Federal Short Cycle; Bounded Errors of Commission Method

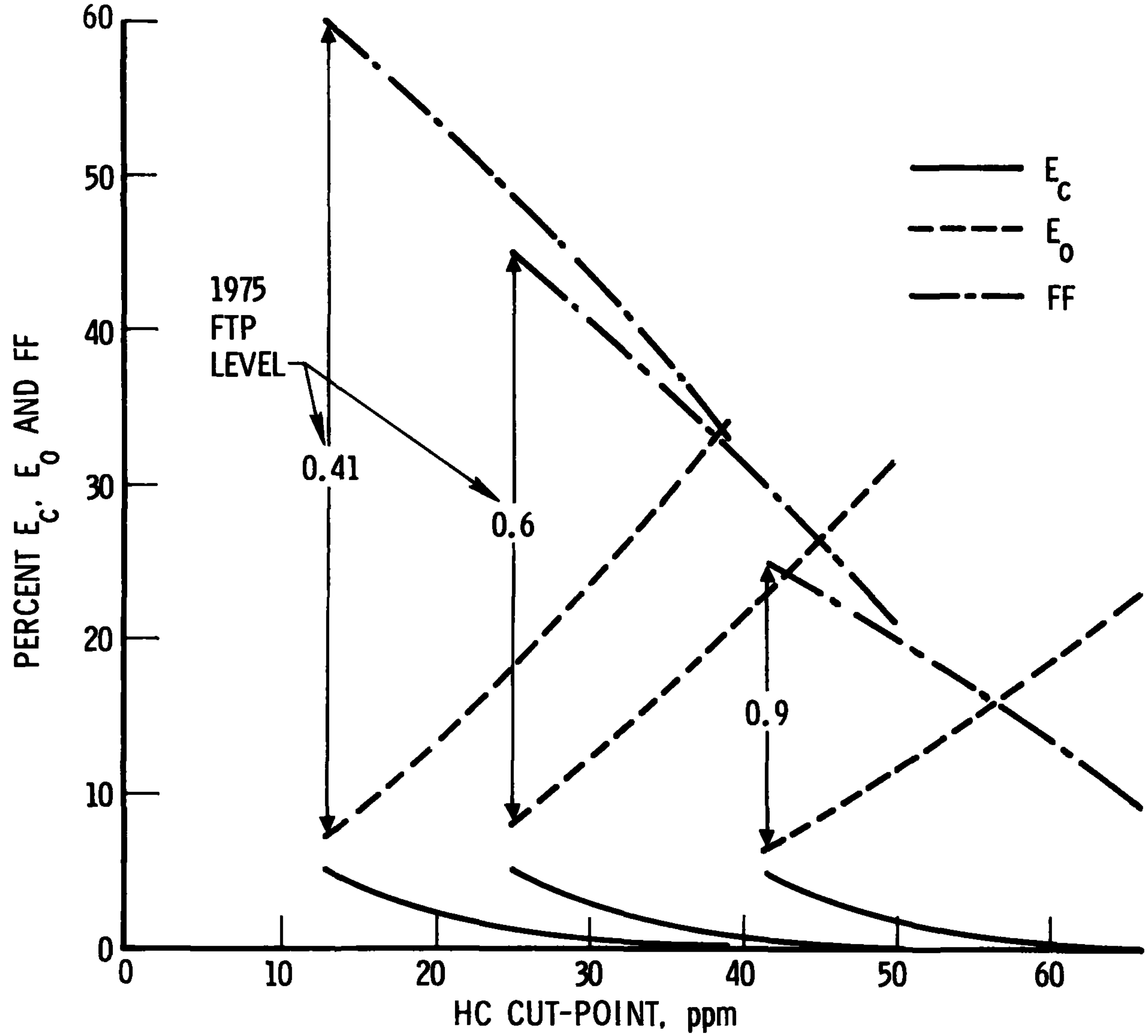


Figure 4-27. Variation of E_C, E_O, and FF with HC Cut-Point; CEV Fleet; NY/NJ Composite Test; Bounded Errors of Commission Method

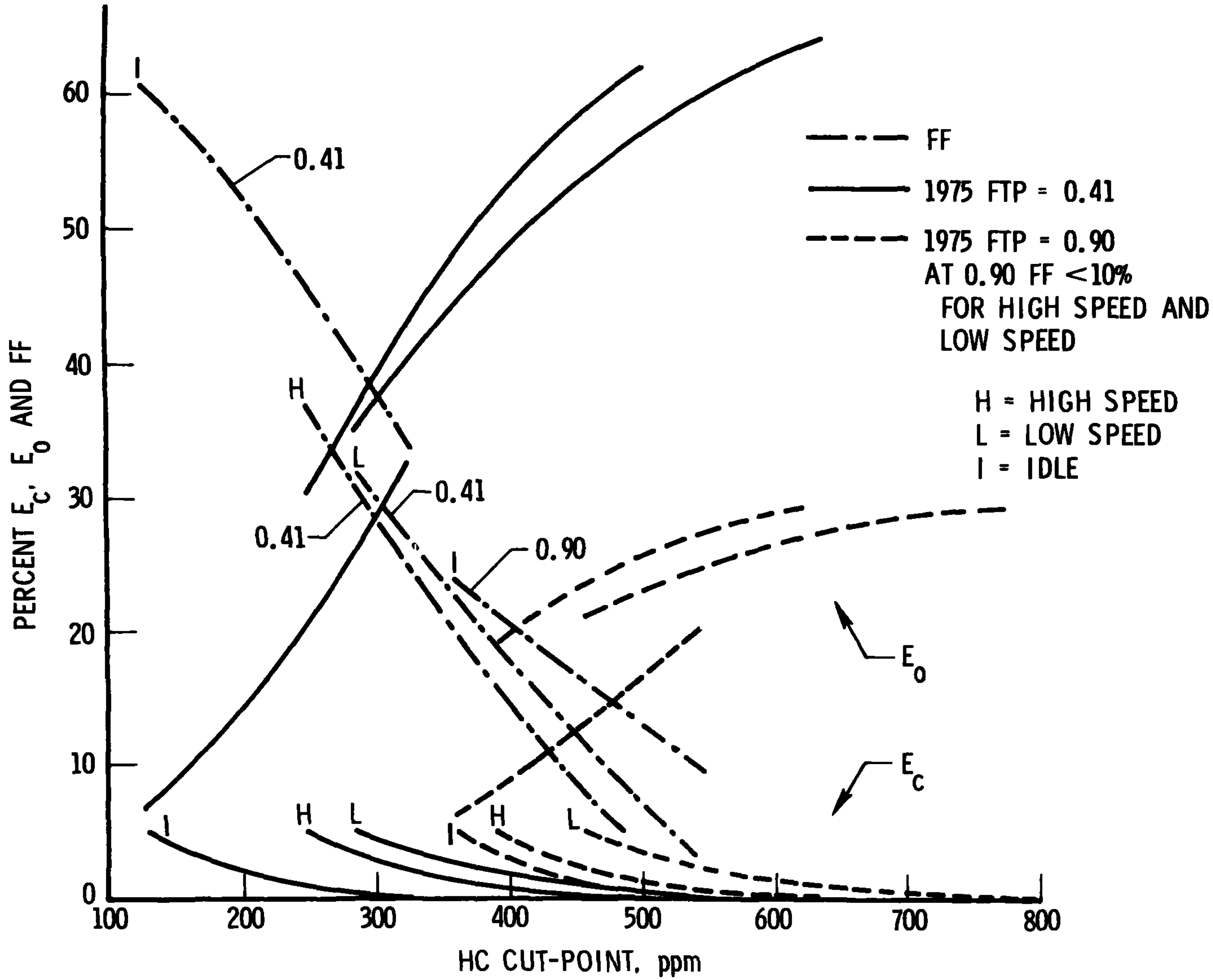


Figure 4-28. Variation of E_c, E_o, and FF with HC Cut-Point; CEV Fleet; Key Mode Test; Bounded Errors of Commission Method

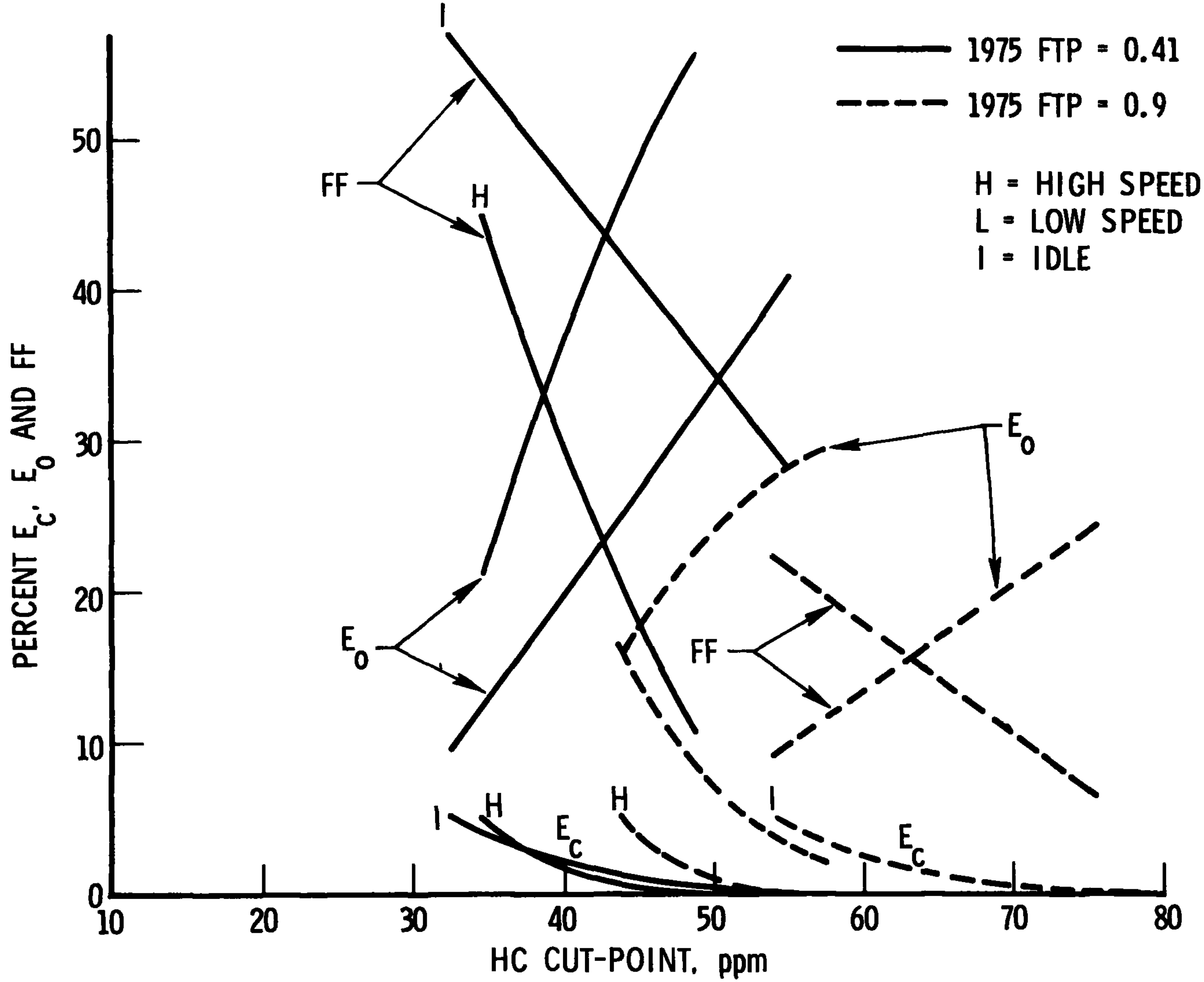


Figure 4-29. Variation of E_C, E_O, and FF with HC Cut-Point; CEV Fleet; Key Mode Test; Garage Instruments; Bounded Errors of Commission Method

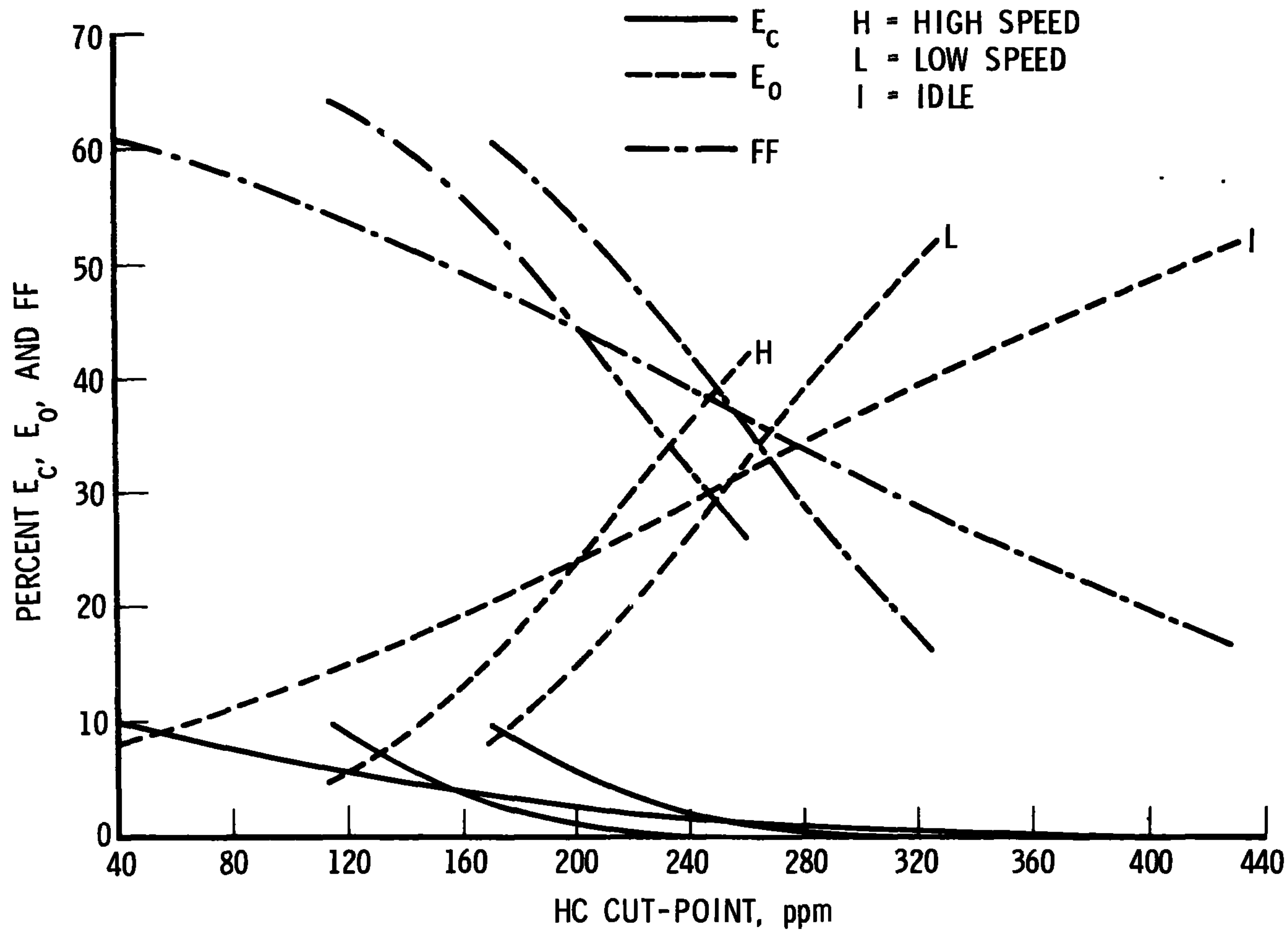


Figure 4-30. Variation of E_C, E_O, and FF with HC Cut-Point; CEV Fleet; 1975 FTP HC Standard = 0.41 gm/mi; Federal Three-Mode Test; Bounded Errors of Commission Method

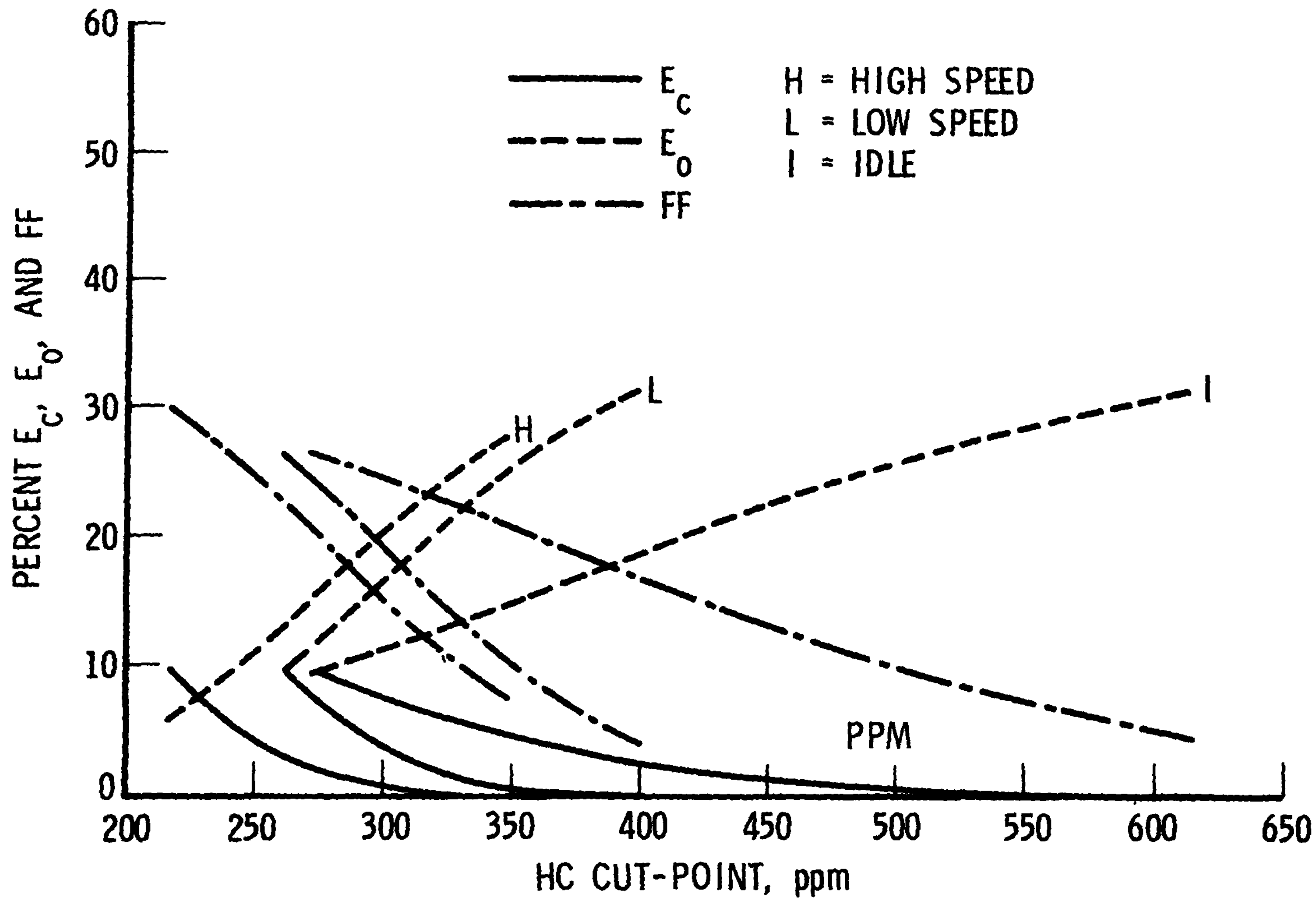


Figure 4-31. Variation of E_C, E_O, and FF with HC Cut-Point; CEV Fleet; 1975 FTP HC Standard = 0.9 gm/mi; Federal Three-Mode Test; Bounded Errors of Commission Method

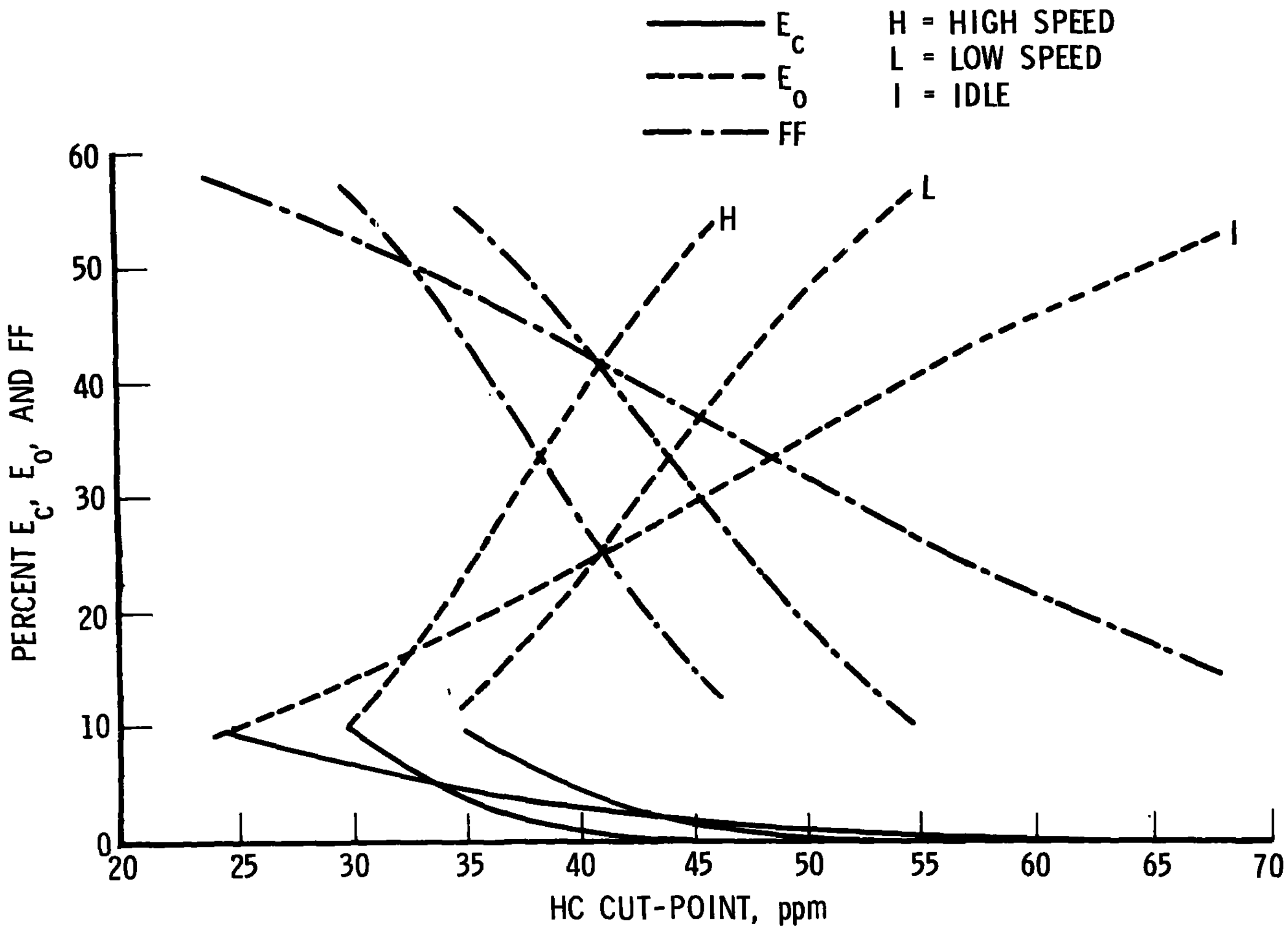


Figure 4-32. Variation of E_c, E_o, and FF with HC Cut-Point; CEV Fleet; 1975 FTP Standard = 0.41 gm/mi; Federal Three-Mode Test; Garage Instruments; Bounded Errors of Commission Method

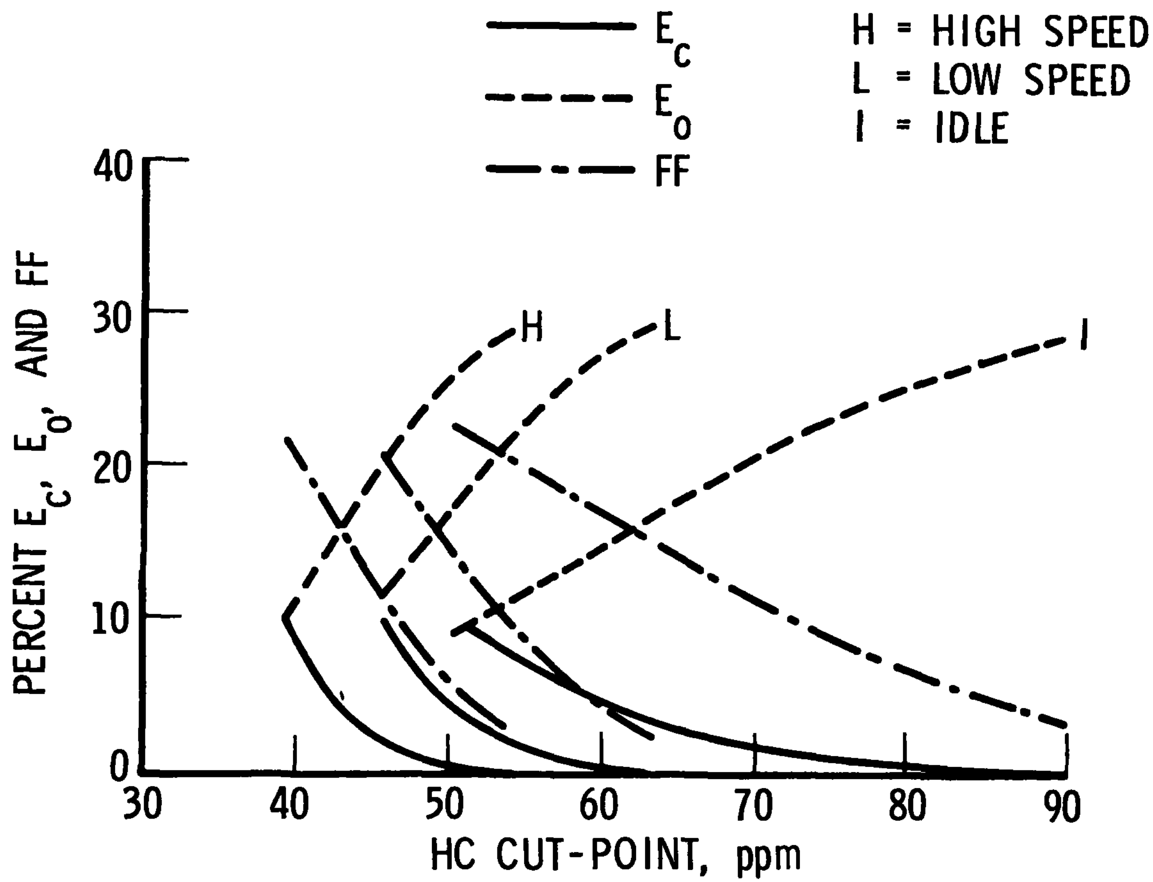


Figure 4-33. Variation of E_c, E_o, and FF with HC Cut-Point; CEV Fleet; 1975 FTP Standard = 0.9 gm/mi; Federal Three-Mode Test; Garage Instruments; Bounded Errors of Commission Method

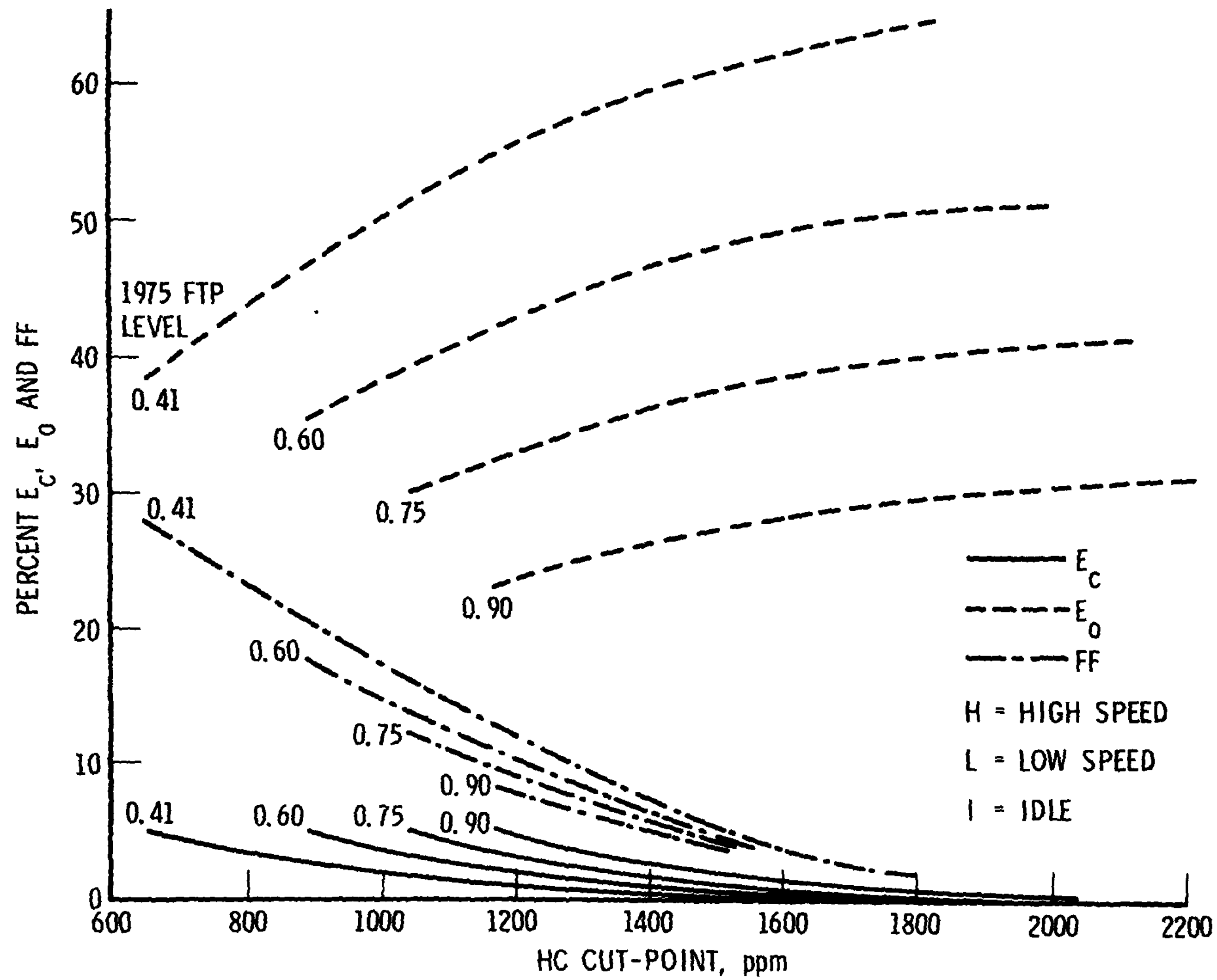


Figure 4-34. Variation of E_C, E_O, and FF with HC Cut-Point; CEV Fleet; Unloaded 2500 rpm Test; Bounded Errors of Commission Method

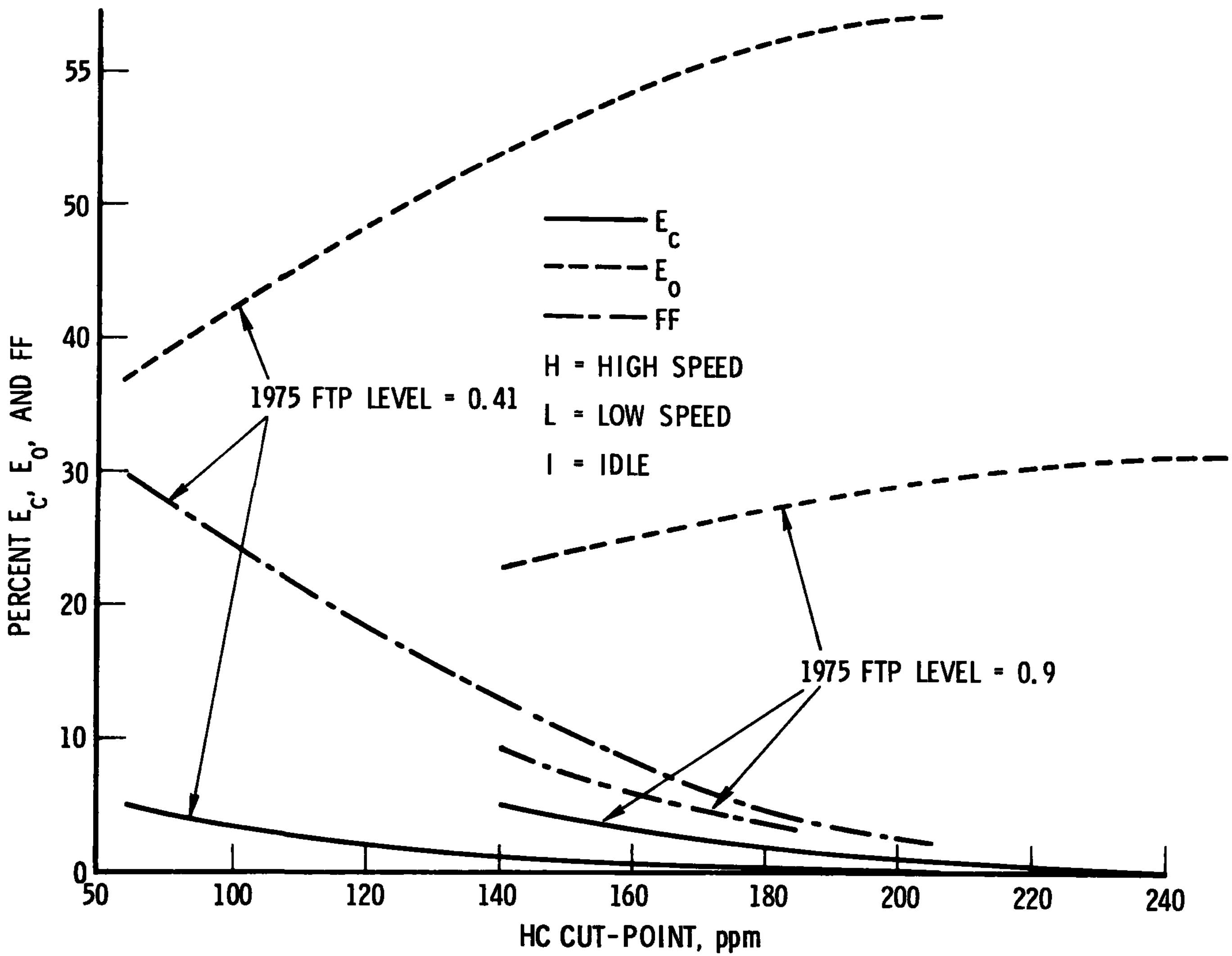


Figure 4-35. Variation of E_c, E_o, and FF with HC Cut-Point; CEV Fleet; Unloaded 2500 rpm Test; Garage Instruments; Bounded Errors of Commission Method

Table 4-15. Comparison of Selected ST Hydrocarbon Results: CEV Fleet, Bounded Errors of Commission Analysis, HC FTP Level = 0.90 gm/mile (E_c = constant = 5%)

Short Test	Parameter, %	
	E_o	FF
Federal Short Cycle	9	22
NY/NJ Composite	6.5	25
Clayton Key Mode (Laboratory)		
Idle	6	22
Low Speed	21	9
High Speed	19.5	10
Clayton Key Mode (Garage)		
Idle	9.5	22
High Speed	16	16
Federal Three-Mode (Laboratory)		
Idle	15	21
Low Speed	15	21
High Speed	10	25
Federal Three-Mode (Garage)		
Idle	14	17
Low Speed	16	16
High Speed	15	17
2500 rpm Unloaded (Laboratory)	23	8
2500 rpm Unloaded (Garage)	23	9

Table 4-16. Comparison of Selected ST Hydrocarbon Results: CEV Fleet, Bounded Errors of Commission Analysis, HC FTP Level = 0.41 gm/mile (E_c = constant = 5%)

Short Test	Parameter, %	
	E_o	FF
Federal Short Cycle	11	56
NY/NJ Composite	7	60
Clayton Key Mode (Laboratory)		
Idle	7	61
Low Speed	35	32
High Speed	30	37
Clayton Key Mode (Garage)		
Idle	10	57
High Speed	21	45
Federal Three-Mode (Laboratory)		
Idle	17	52
Low Speed	17	38
High Speed	11	51
Federal Three-Mode (Garage)		
Idle	18	46
Low Speed	22	44
High Speed	20	47
2500 rpm Unloaded (Laboratory)	38	28
2500 rpm Unloaded (Garage)	37	30

summarize data from the figures at HC FTP levels of 0.41 and 0.90. On the average, at both FTP levels, the bag tests (Federal Short Cycle and NY/NJ Composite) have lower E_o and higher FF at the fixed E_c = 5 percent than do the volumetric tests. However, the idle mode of the Clayton Key Mode (with either laboratory or garage instruments) test produces similar results. The 2500 rpm Unloaded test is very poor on a comparative basis.

4.2.2.5.1.2 Carbon Monoxide Emissions

The variation of E_o, E_c, and FF as a function of CO cut-point are displayed in Figures 4-36 through 4-43 for each ST examined, and for the range of CO FTP values selected in Table 4-10 (CO = 3.4 to 9.0). The figures correspond to the following ST/FTP-level spectrum:

Short Test	CO FTP Level				Figure No.
	3.4	5.0	7.0	9.0	
Federal Short Cycle	X	X	X	X	4-36
NY/NJ Composite	X	X	X	X	4-37
Clayton Key Mode (Laboratory)	X			X	4-38
Clayton Key Mode (Garage)	X			X	4-39
Federal Three-Mode (Laboratory)	X			X	4-40
Federal Three-Mode (Garage)	X			X	4-41
2500 rpm Unloaded (Laboratory)	X	X	X	X	4-42
2500 rpm Unloaded (Garage)	X			X	4-43

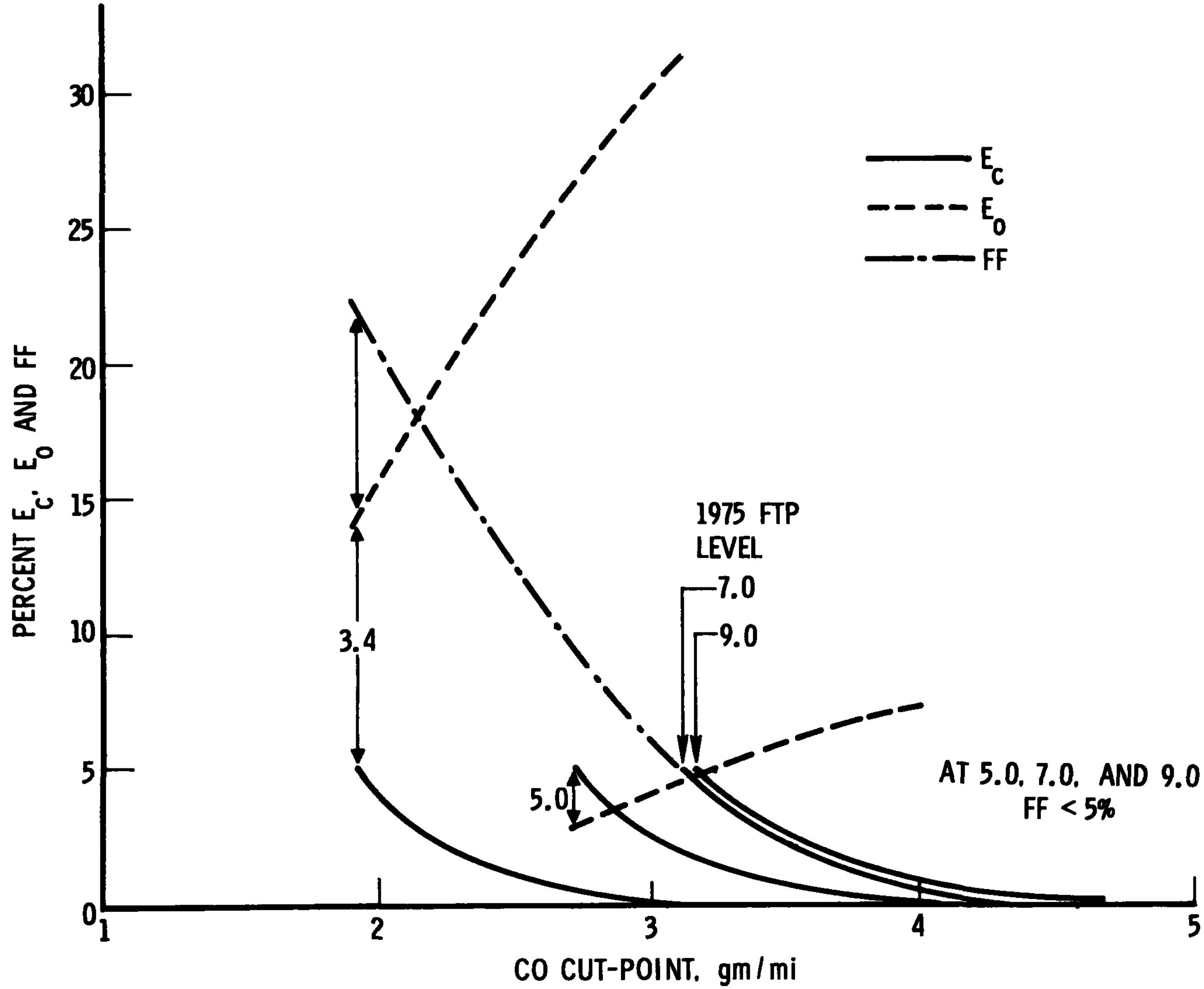


Figure 4-36. Variation of E_C, E_O, and FF with CO Cut-Point; CEV Fleet; Federal Short Cycle; Bounded Errors of Commission Method

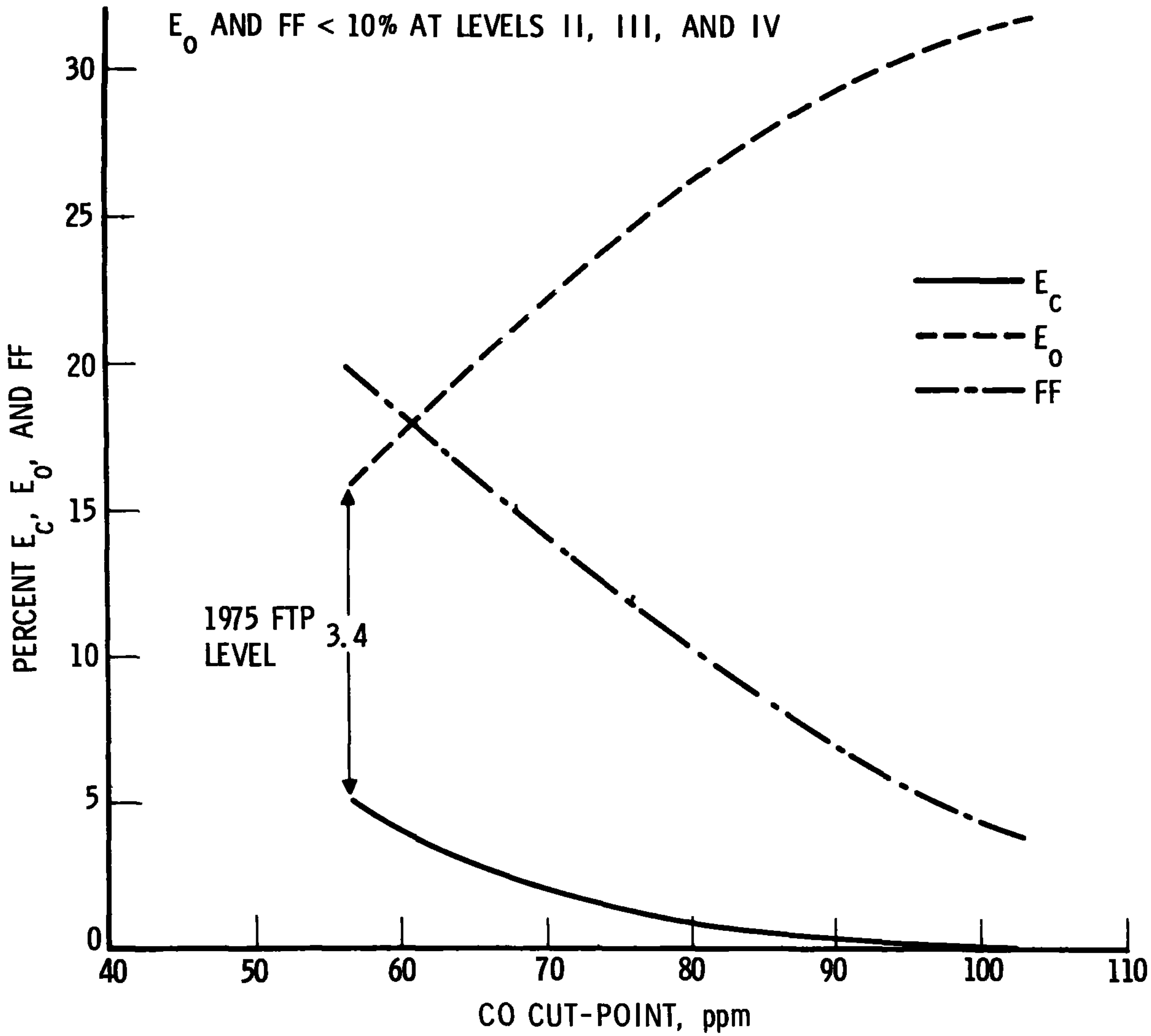


Figure 4-37. Variation of E_c, E_o, and FF with CO Cut-Point; CEV Fleet; 1975 FTP CO Level = 3.4 gm/mi; NY/NJ Composite Test; Bounded Errors of Commission Method

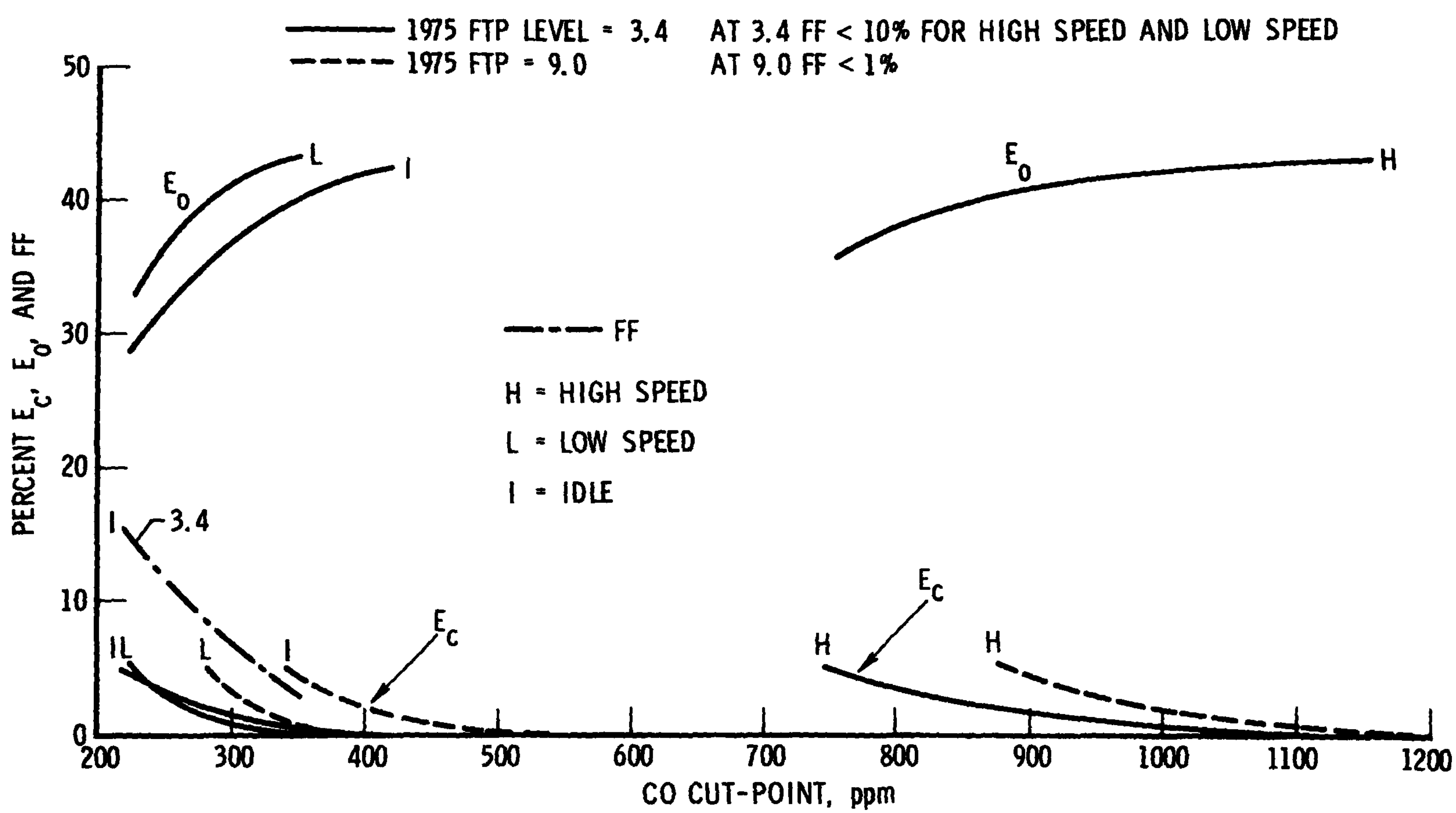


Figure 4-38. Variation of E_c, E_o, and FF with CO Cut-Point; CEV Fleet; Key Mode Test; Bounded Errors of Commission Method

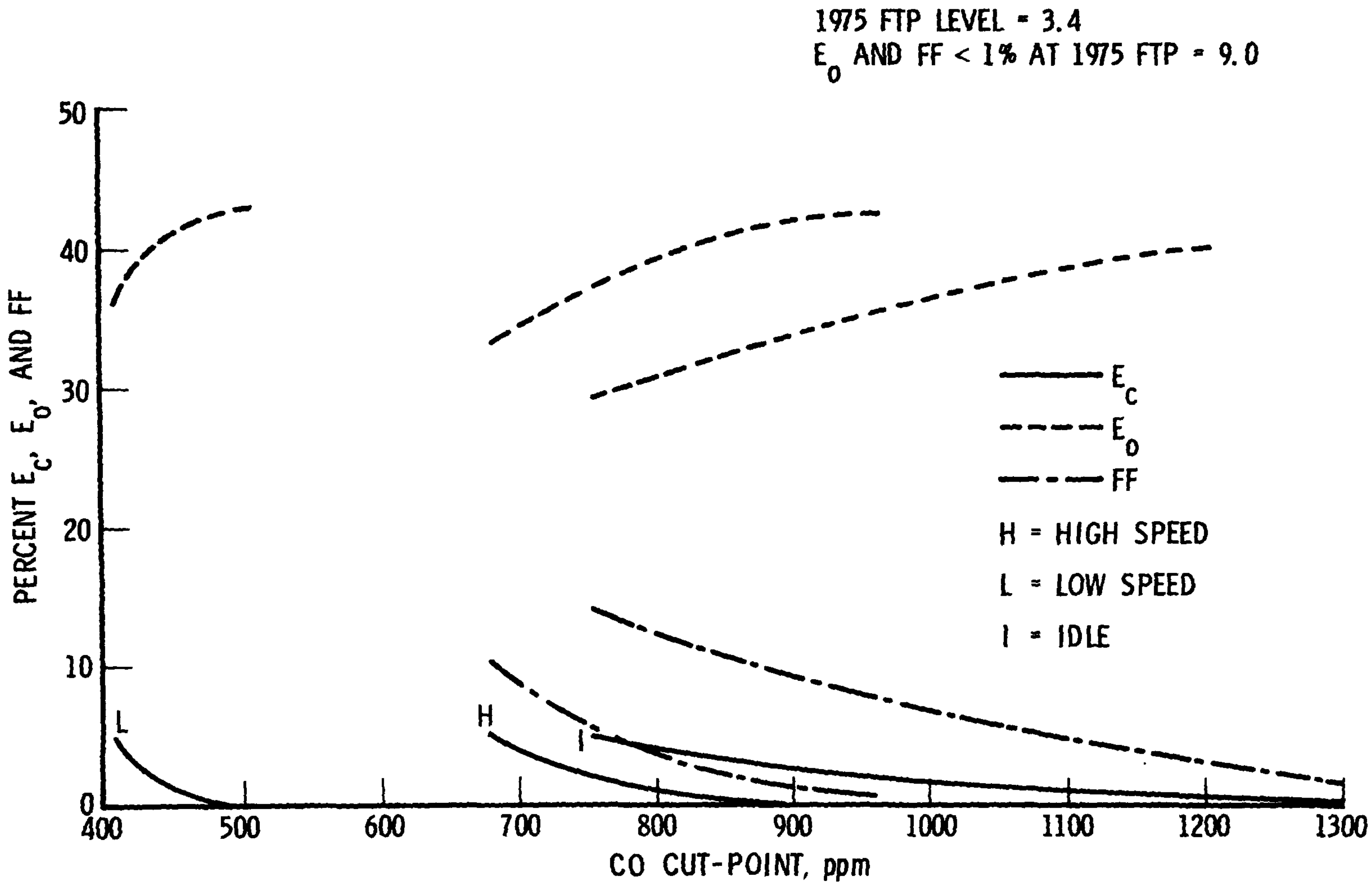


Figure 4-39. Variation of E_c, E_o, and FF with CO Cut-Point; CEV Fleet; Key Mode Test; Garage Instruments; Bounded Errors of Commission Method

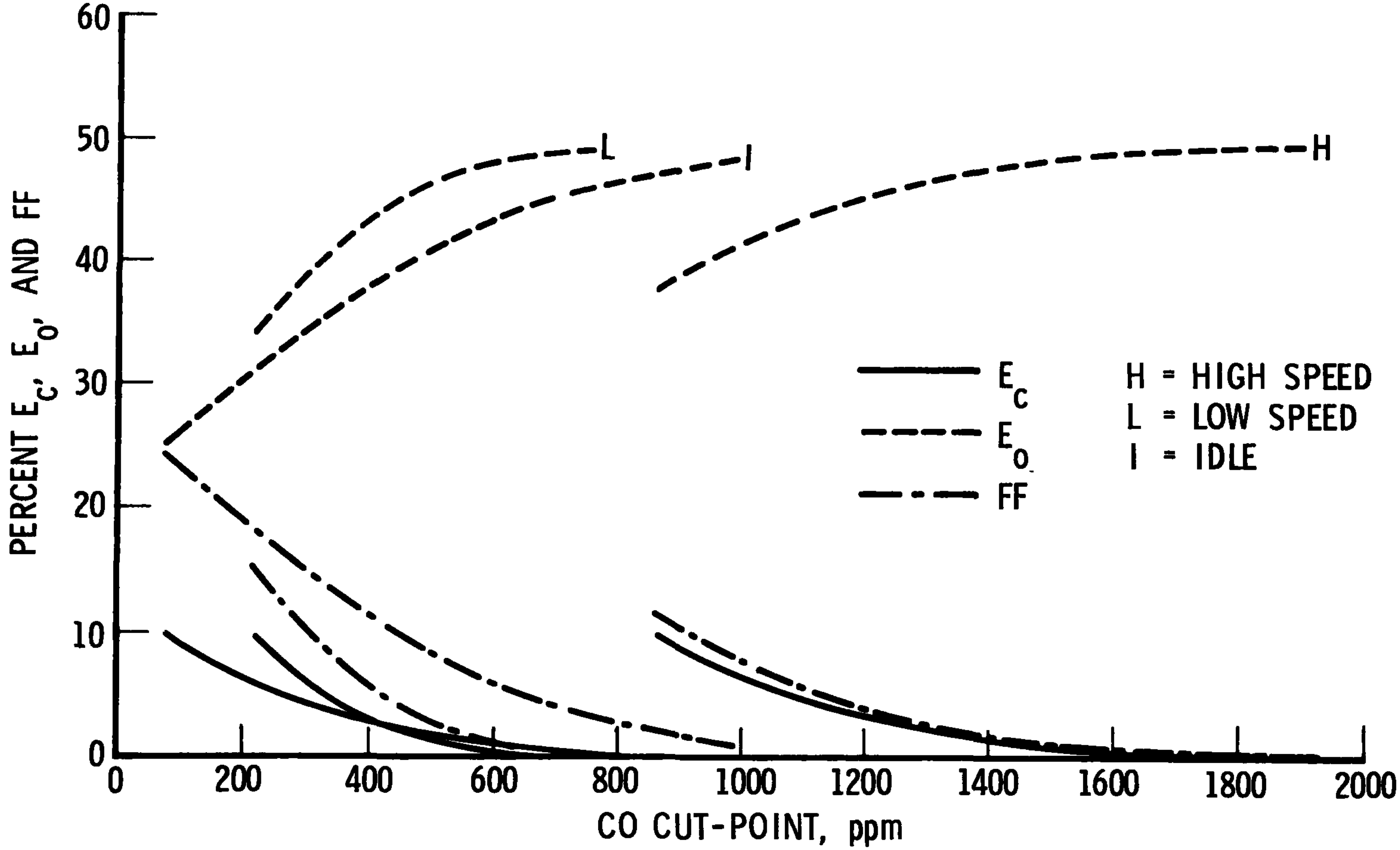


Figure 4-40. Variation of E_c, E_o, and FF with CO Cut-Point; CEV Fleet; 1975 FTP CO Level = 3.4 gm/mi; Federal Three-Mode Test; Bounded Errors of Commission Method

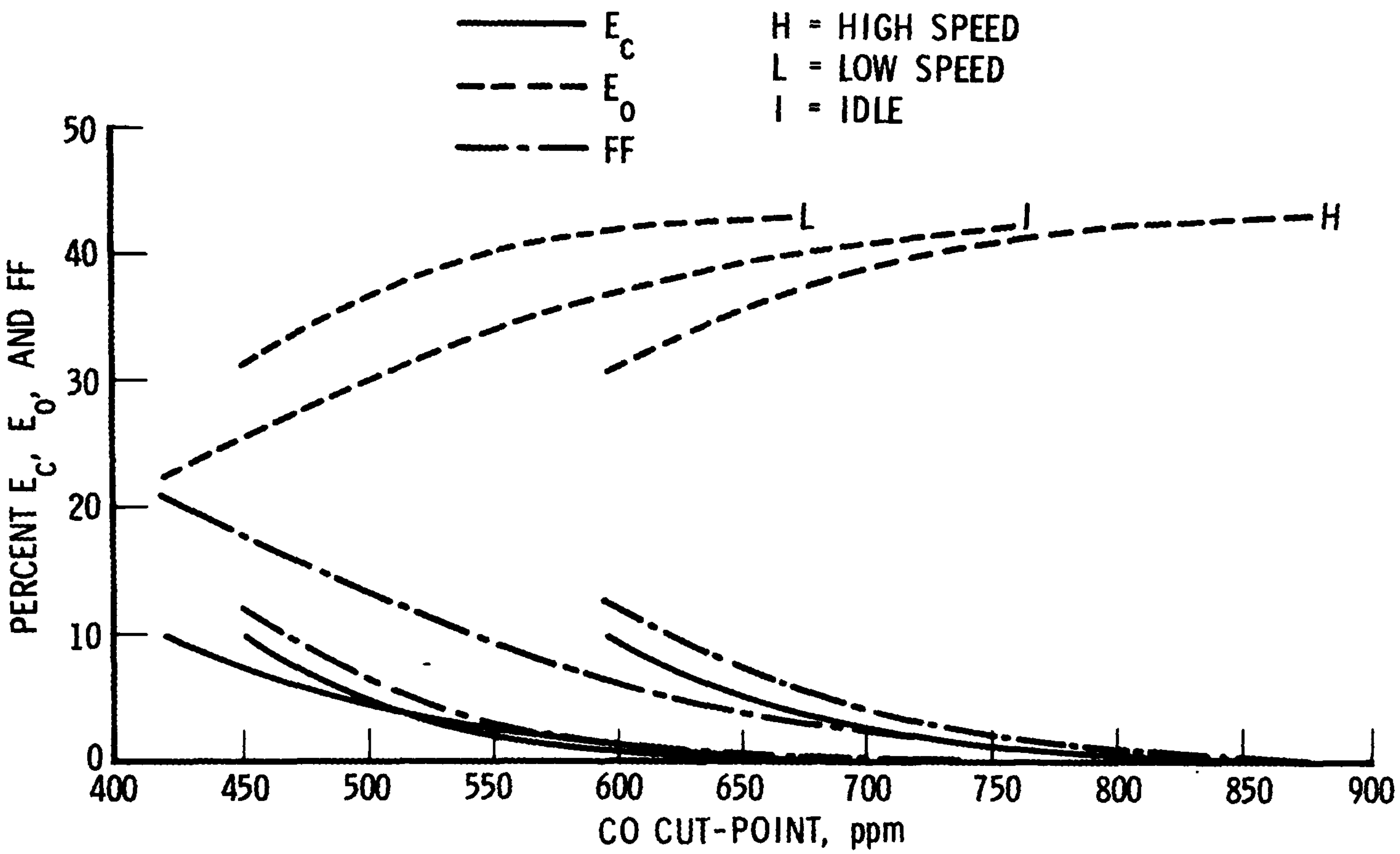


Figure 4-41. Variation of E_c, E_o, and FF with CO Cut-Point; CEV Fleet; 1975 FTP Level = 3.4 gm/mi; Federal Three-Mode Test; Garage Instruments; Bounded Errors of Commission Method

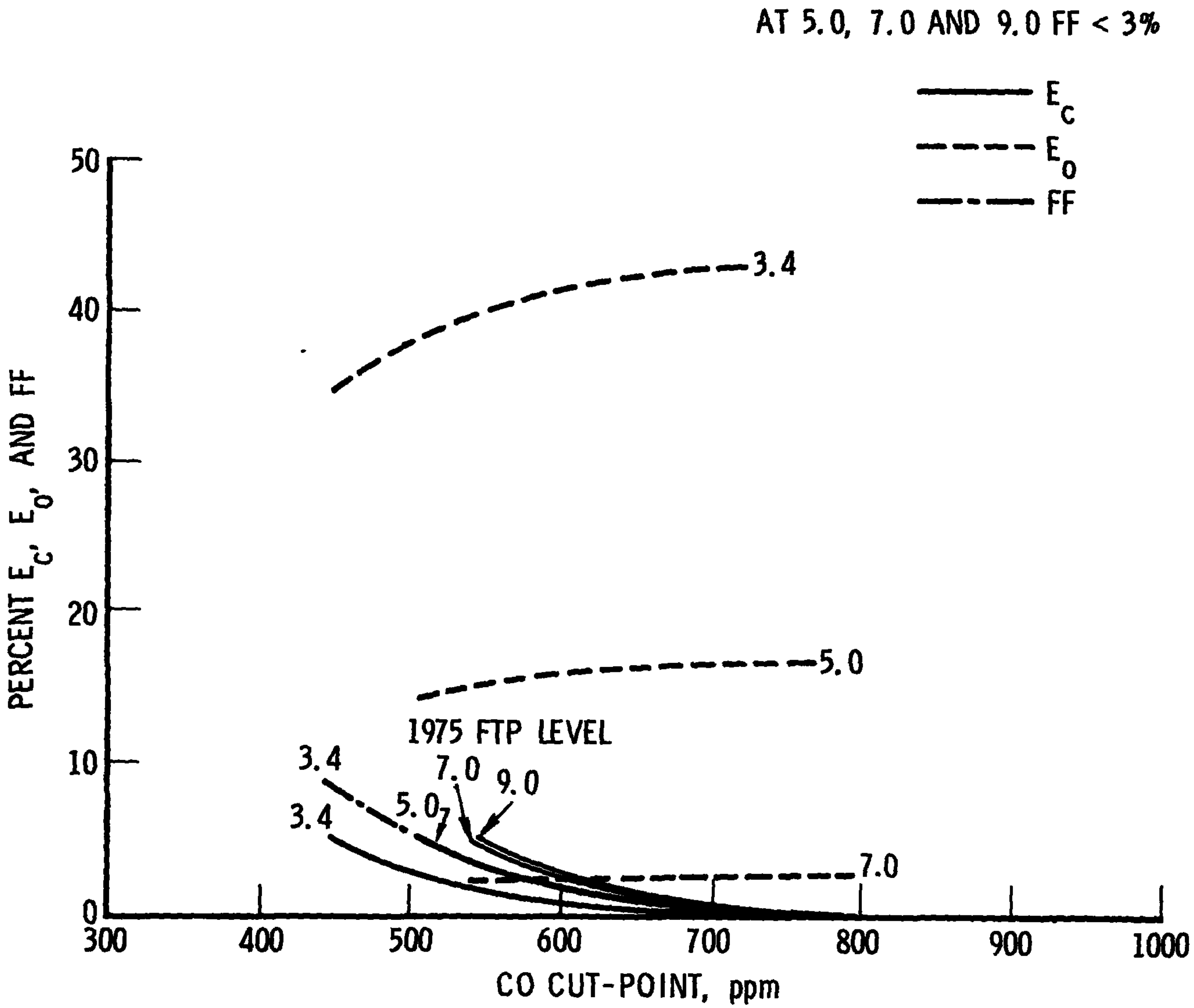


Figure 4-42. Variation of E_c, E_o, and FF with CO Cut-Point; CEV Fleet; Unloaded 2500 rpm Test; Bounded Errors of Commission Method

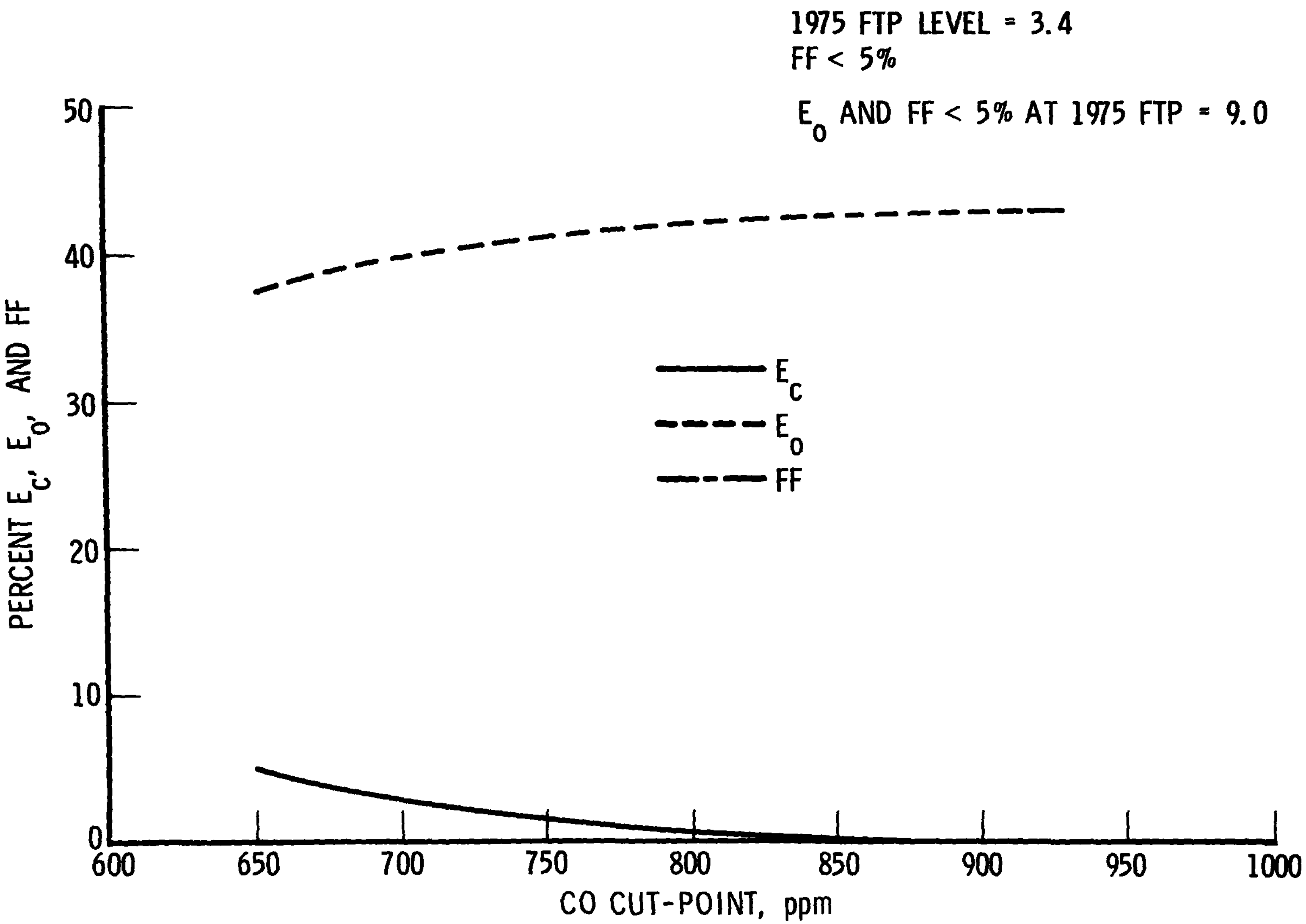


Figure 4-43. Variation of E_C, E_O, and FF with CO Cut-Point; CEV Fleet; Unloaded 2500 rpm Test; Garage Instruments; Bounded Errors of Commission Method

As in the preceding case of hydrocarbon emissions, these figures indicate the tradeoffs possible between E_c, E_o, and FF. However, for CO FTP levels above 3.4, the general or average CO levels of the CEV fleet were sufficiently low, i.e., a very high percentage of the vehicles were better than the 5.0, 7.0, and 9.0 gm/mi requirements, that both E_o and FF percentage values were very small for all of the short test procedures. This characteristic is summarized in Table 4-17 for the CO FTP level of 9.0 gm/mi.

At the 3.4 level, however, as shown in Table 4-18, the bag tests were sufficiently discriminatory to identify FF values above 20 percent, with E_o values in the 14- to 16-percent range. The volumetric tests, on the other hand, all had high E_o values (30- to 40-percent range) with very low FF values (< 16).

4.2.2.5.1.3 Oxides of Nitrogen Emissions

The variations of E_o, E_c, and FF as a function of NO_x cutpoint are displayed in Figures 4-44 through 4-48 for each ST examined, for the single NO_x FTP values of 3.1 gm/mi examined in the study.

The significant results at the E_c level of 5 percent are summarized in Table 4-19 for comparative purposes. As shown, the high-speed mode of the volumetric tests (Clayton Key Mode and Federal Three-Mode) produced the highest FF values and the lowest E_o values, and are thus indicated to be superior for NO_x discrimination purposes.

4.2.2.5.1.4 Weighted Three-Mode Tests

In addition, a bounded errors analysis was made for two weighted Key Mode tests. The first weighting factors were based on the multiple regression analysis of Sec. 4.2.1.2. The second weighting factors are suggested by Clayton Manufacturing Co.[1] These latter factors were developed for HC and CO, based on 1972 surveillance data. The weighting factors are given in Table 4-20. The analysis was performed at FTP level I

[1] "Exhibit G, Short Tests Versus 1975 CVS Relatability Analysis/Correlation/Errors of Commission and Omission," May 1973

Table 4-17. Comparison of Selected ST Carbon Monoxide Results: CEV Fleet, Bounded Errors of Commission Analysis, CO FTP Level = 9.0 gm/mi (E_c = constant = 5%)

Short Test	Parameter, %	
	E_o	FF
Federal Short Cycle	< 1	< 1
NY/NJ Composite	< 1	< 1
Clayton Key Mode (Laboratory)		
Idle	< 1	< 1
Low Speed	< 1	< 1
High Speed	< 1	< 1
Clayton Key Mode (Garage)		
Idle	< 1	< 1
Low Speed	< 1	< 1
High Speed	< 1	< 1
Federal Three-Mode (Laboratory)		
Idle	< 1	< 1
Low Speed	< 1	< 1
High Speed	< 1	< 1
Federal Three-Mode (Garage)		
Idle	< 1	< 1
Low Speed	< 1	< 1
High Speed	< 1	< 1
2500 rpm Unloaded (Laboratory)	< 1	< 1
2500 rpm Unloaded (Garage)	< 1	< 1

Table 4-18. Comparison of Selected ST Carbon Monoxide Results: CEV Fleet, Bounded Errors of Commission Analysis, CO FTP Level = 3.4 gm/mi (E_c = constant = 5%)

Short Test	Parameter, %	
	E_o	FF
Federal Short Cycle	14	22
NY/NJ Composite	16	20
Clayton Key Mode (Laboratory)		
Idle	29	15
Low Speed	33	11
High Speed	36	8
Clayton Key Mode (Garage)		
Idle	29	14
Low Speed	36	7
High Speed	33	10
Federal Three-Mode (Laboratory)		
Idle	33	16
Low Speed	40	8
High Speed	43	7
Federal Three-Mode (Garage)		
Idle	29	14
Low Speed	36	7
High Speed	36	7.5
2500 rpm Unloaded (Laboratory)	35	8
2500 rpm Unloaded (Garage)	38	6

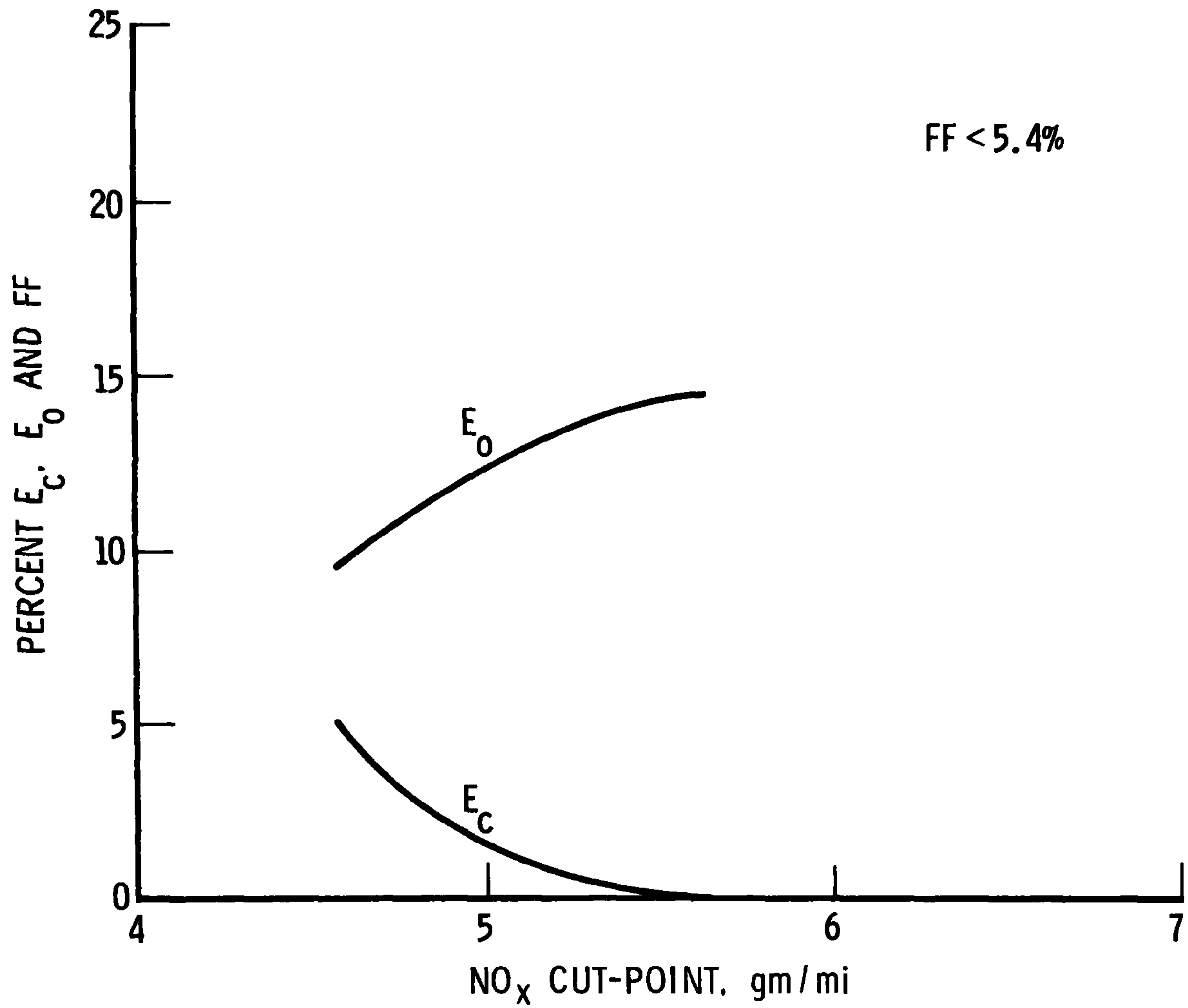


Figure 4-44. Variation of E_c, E_o, and FF with NO_x Cut-Point; CEV Fleet; Federal Short Cycle Test; Bounded Errors of Commission Method

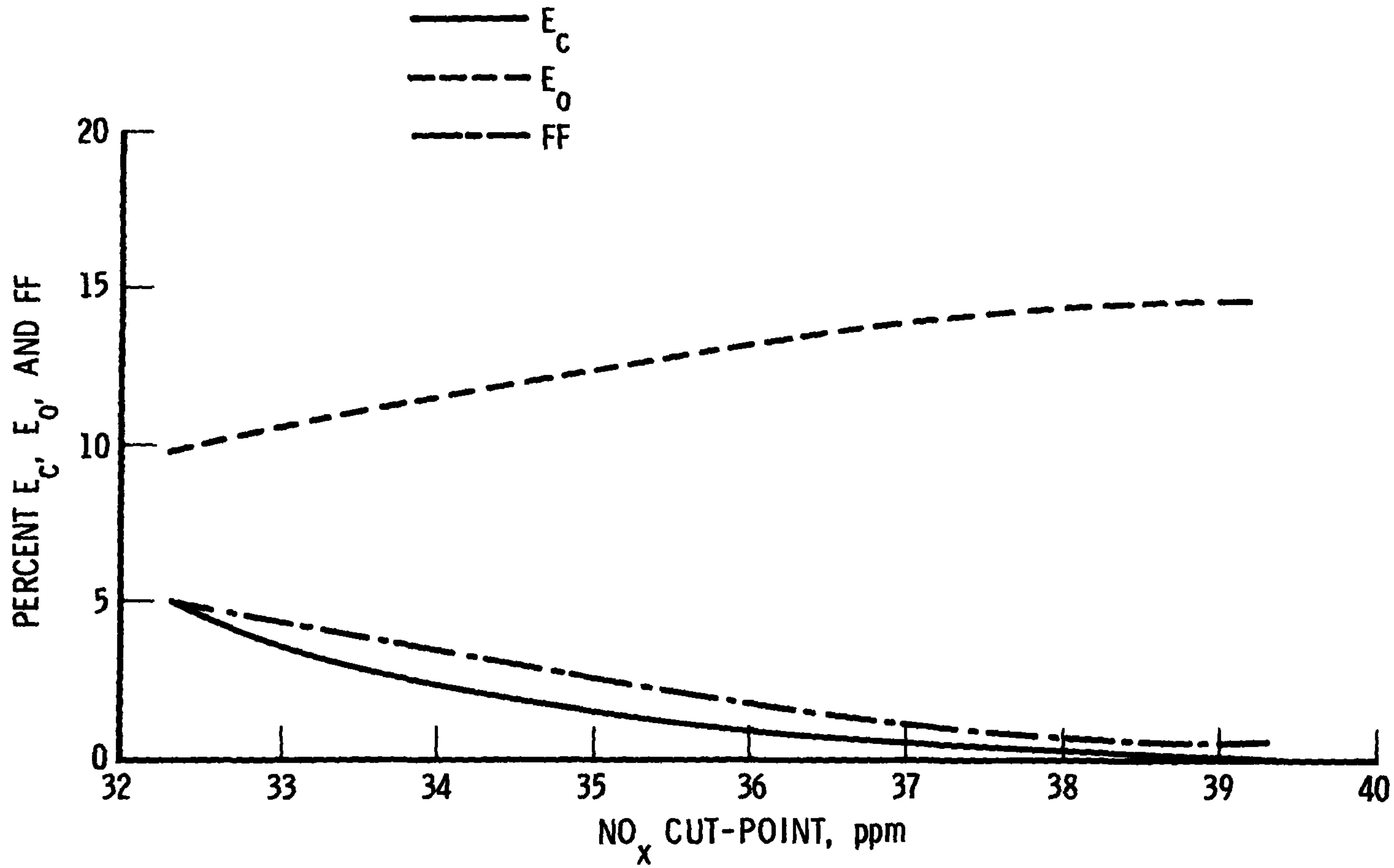


Figure 4-45. Variation of E_c, E_o, and FF with NO_x Cut-Point; CEV Fleet; NY/NJ Composite Test; Bounded Errors of Commission Method

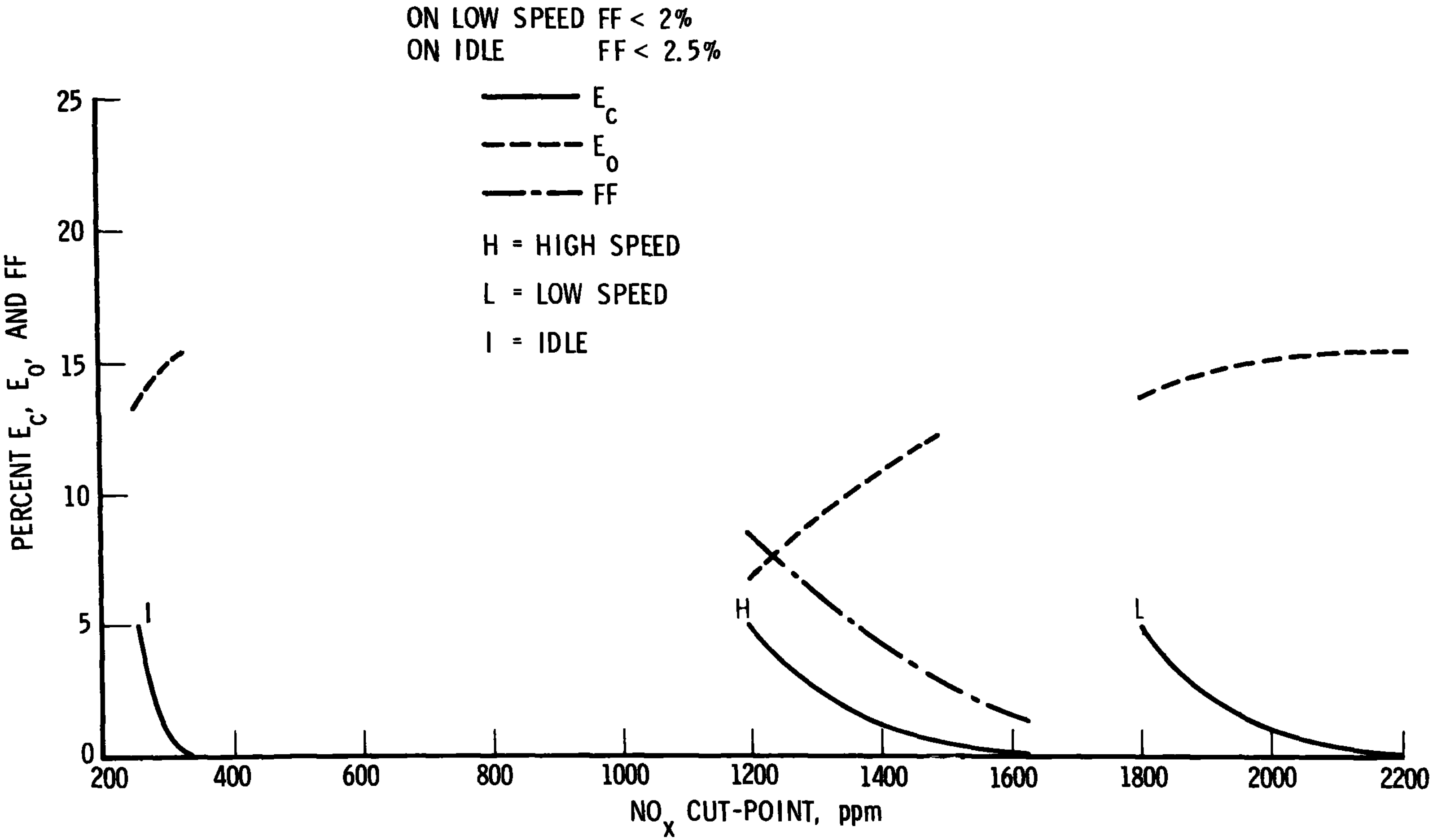


Figure 4-46. Variation of E_c, E_o, and FF with NO_x Cut-Point; CEV Fleet; Key Mode Test; Bounded Errors of Commission Method

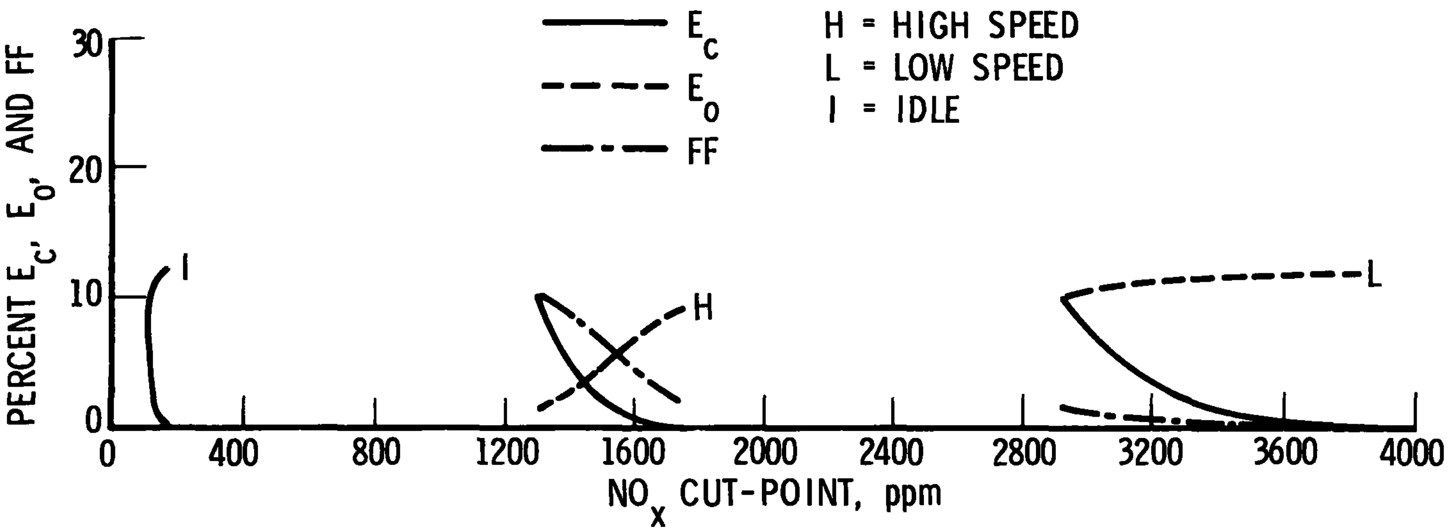


Figure 4-47. Variation of E_c, E_o, and FF with NO_x Cut-Point; CEV Fleet; Federal Three-Mode Test; Bounded Errors of Commission Method

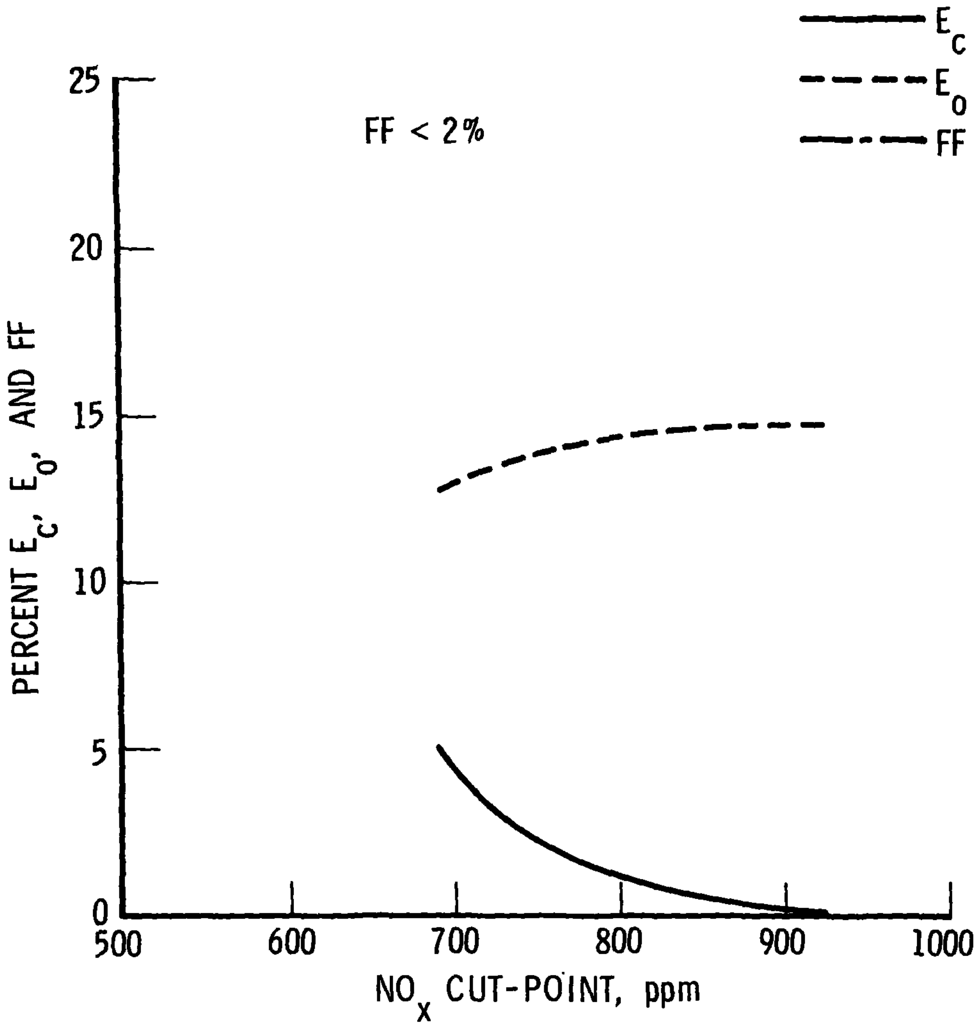


Figure 4-48. Variation of E_c, E_o, and FF with NO_x Cut-Point; CEV Fleet; Unloaded 2500 rpm Test; Bounded Errors of Commission Method

Table 4-19. Comparison of Selected ST NO_x Results: CEV Fleet, Bounded Errors of Commission Analysis, NO_x FTP Level = 3.1 gm/mi (E_c = constant = 5%)

Short Test	Parameter, %	
	E_o	FF
Federal Short Cycle	9.5	5.5
NY/NJ Composite	10	5
Clayton Key Mode (Laboratory)[a]		
Idle	13	2
Low Speed	14	< 2
High Speed	6.5	8.5
Federal Three-Mode (Laboratory)[a]		
Idle	11	1
Low Speed	11	1
High Speed	3	8.5
2500 rpm Unloaded (Laboratory)[a]	13	2

(a) Garage-type analyzers for NO_x were not available for ST evaluation.

Table 4-20. Key Mode Weighting Factors

Origin	Mode	Weights		
		HC	CO	NO_x
Regression Analysis	High	0.00025	6.67	0.00116
	Low	0.00017	- 1.79	0.00024
	Idle	0.00174	72.65	0.00204
	Constant	0.154	2.07	0.929
Clayton Report	High	0.8736	0.66	---
	Low	0.8736	0.66	---
	Idle	0.312	0.33	---
	Constant	---	---	---

only (see Table 4-10). The results are depicted in Figures 4-49 to 4-51. They clearly illustrate that the weighted volumetric tests are not significantly better than the best single mode.

4.2.2.5.1.5 Variance Estimates

As the plots in Figures 4-26 to 4-48 are predictions from the data, the variability of these predictions should be addressed. Referring to Figures 4-7 and 4-9, the problem of estimating the ST cut-point, for a fixed FTP level, is analogous to estimating the quantiles of a distribution function (Ref. 4-5). Thus, the large sample standard deviation is given by

$$\frac{PF}{\left|\frac{dp(y)}{dy}\right|_{y = LS_o}} \sqrt{\frac{\gamma(1 - \gamma)}{N}} \qquad (4\text{-}1)$$

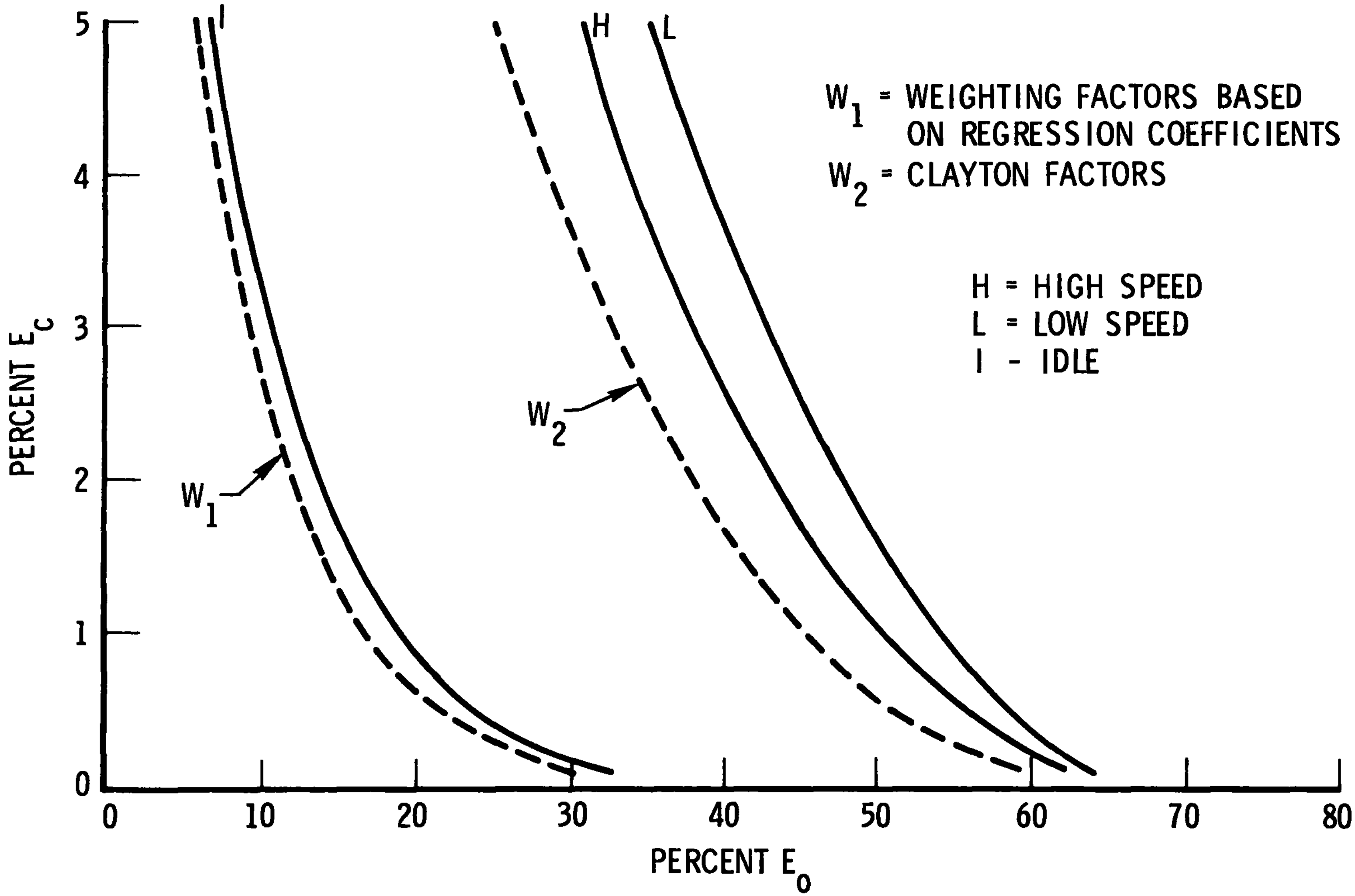


Figure 4-49. Variation of E_c and E_o for Key Mode and Weighted Key Mode Tests; CEV Fleet; 1975 FTP HC Level = 0.41 gm/mi; Bounded Errors of Commission Method

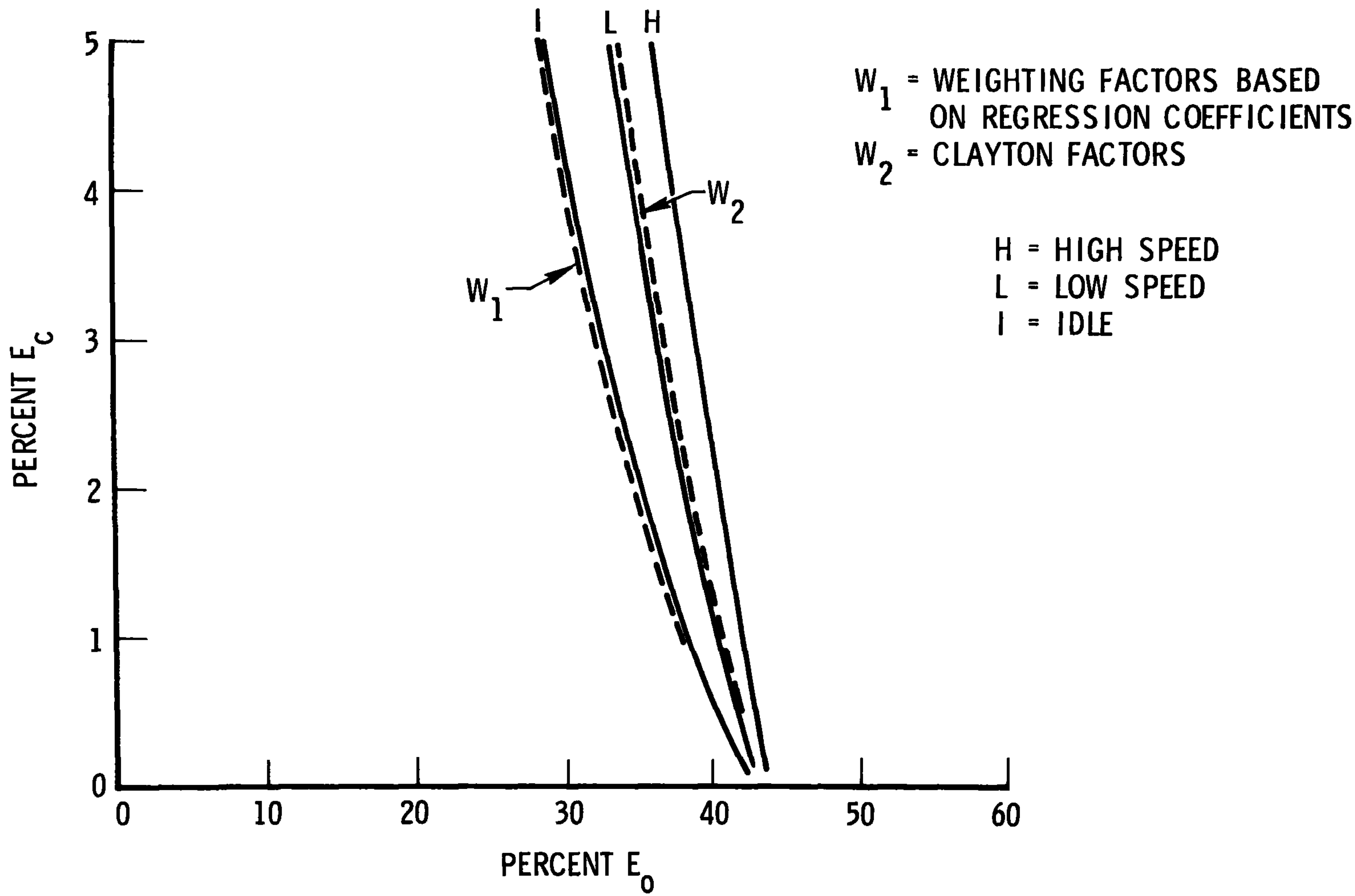


Figure 4-50. Variation of E_o and E_c for Key Mode and Weighted Key Mode Tests; CEV Fleet; 1975 FTP CO Level = 3.4 gm/mi; Bounded Errors of Commission Method

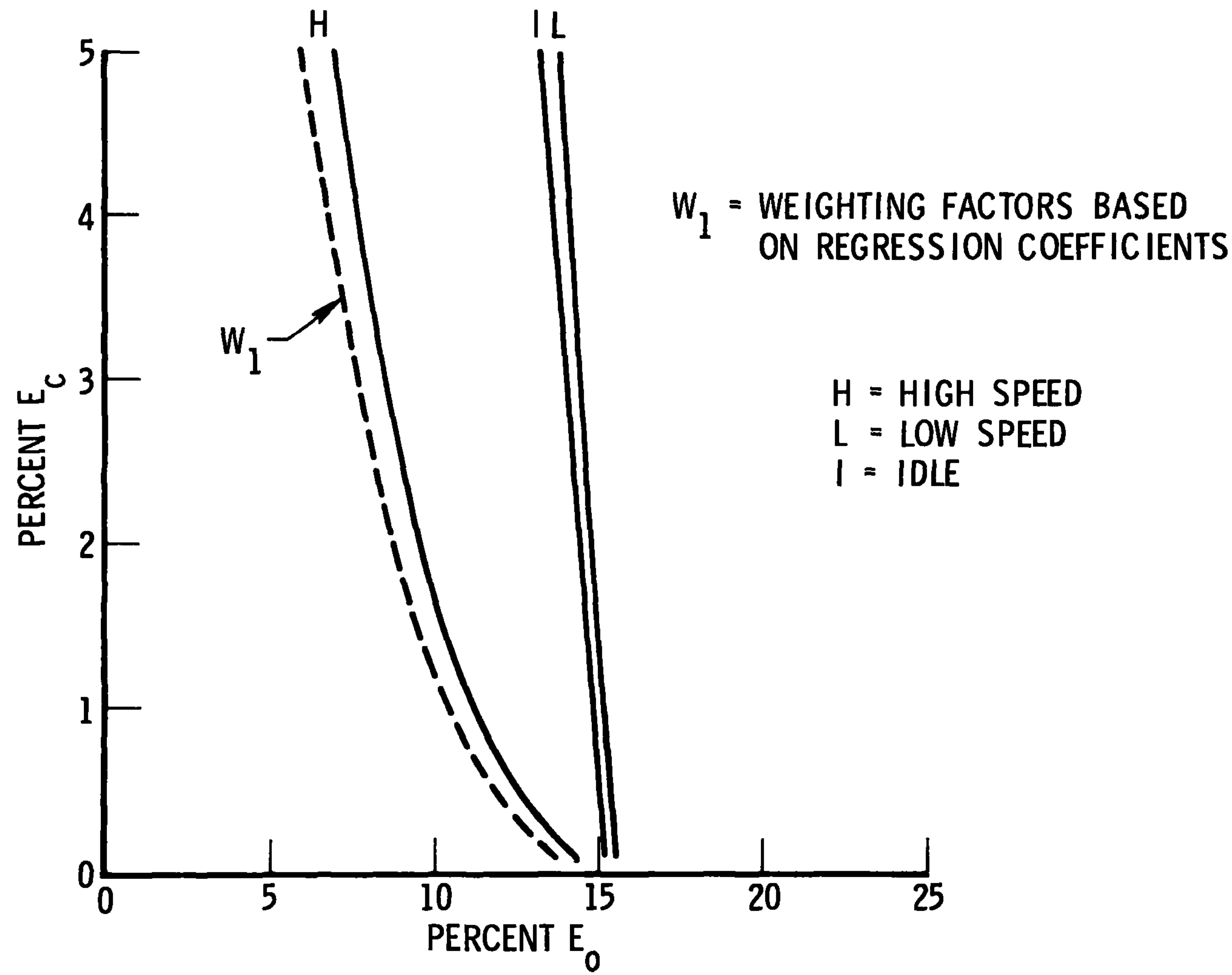


Figure 4-51. Variation of E_o and E_c for Key Mode and Weighted Key Mode Tests; CEV Fleet; 1975 FTP NO_x Level = 3.1 gm/mi; Bounded Errors of Commission Method

where

PF = probability of passing the FTP

p(y) = probability of an error of commission for ST cut-point set at value y

γ = upper bound on probability of errors of commission

N = sample size or number of cars in the data set

LS_o = true cut-point for the population.

As PF, p(y), and LS_o are unknown, they can only be approximated from the data. LS_o is, of course, approximated by the cut-point estimated from the data. PF is estimated on the percent passed by FTP divided by 100. p(y) is taken to be the locus of E_c versus cut-point. $\left|dp(y)/dy\right|_{LS_o}$ is taken as the derivative of the E_c versus cut-point curve evaluated at the cut-point of interest $\left(LS_o\right)$. Equation (4-1) will be used to discuss variablility of the predicted population.

For a fixed FTP level, the standard deviation of the estimated cut-point can be independently controlled by increasing the sample size. Once the sample size is fixed, this standard deviation varies inversely with the magnitude of the derivative of the E_c versus cut-point curve. Thus, in regions where the curve is steep, the variability of the predictions will be less than in regions where the curve is flat.

For example, at FTP level for HC = 0.41 and Federal Short Cycle cut-point of 0.4, $\gamma \simeq 0.045$, N = 39, PF = 0.33, and

$$\left|\frac{dp(y)}{dy}\right|_{0.41} \simeq 0.25$$

Thus, Eq. (4-1) gives the approximate standard deviation of 0.044 gm/mi.

For the Federal Short Cycle point of 0.75,

$$\left|\frac{dp(y)}{dy}\right|_{0.75} \simeq 0.033 \qquad , \qquad \gamma \cong 0.003$$

and the standard deviation increases to 0.086 gm/mi. Figure 4-52 illustrates the effect of the cut-point uncertainty on the other computed quantities of E_o and FF. It shows that the uncertainty in the predicted results increases with decreasing errors of commission bounds.

4.2.2.5.2 Multiple-Constituent Tests

In addition to analyzing each pollutant individually, an analysis was made for multiple-constituent tests, using the contingency table approach. In a three-constituent test, a car fails the ST if any of its HC, CO, and NO_x measurements exceed the previously determined cut-points. These tests are applicable to the bag tests, the unloaded test, and the individual modes of the three-mode volumetric tests. Nine constituent tests are applicable only to the three-mode volumetric tests. A car fails the ST if any one of the modes fails on its three-constituent tests. Only data analytic and parametric actual results were computed. A model for predicting population results was not available.

Shown in Figure 4-53 is the computational procedure followed in determining the multiple constituent tests. Note that the cut-point selection policy is applied at the pollutant level and not at the multiple-constituent test level. For example, the percent E_c is bounded for individual pollutants in the method of bounded errors of commission, and this bound can possibly be exceeded on a multiple-constituent test. In forming the multiple-constituent test contingency table, the following definitions apply:

Correctly passed (PP):	Car passes the ST and the FTP
Correctly failed (FF):	Car fails the ST and the FTP
Error of Commission (E_c):	Car fails the ST and passes the FTP
Error of Omission (E_o):	Car passes the ST and fails the FTP

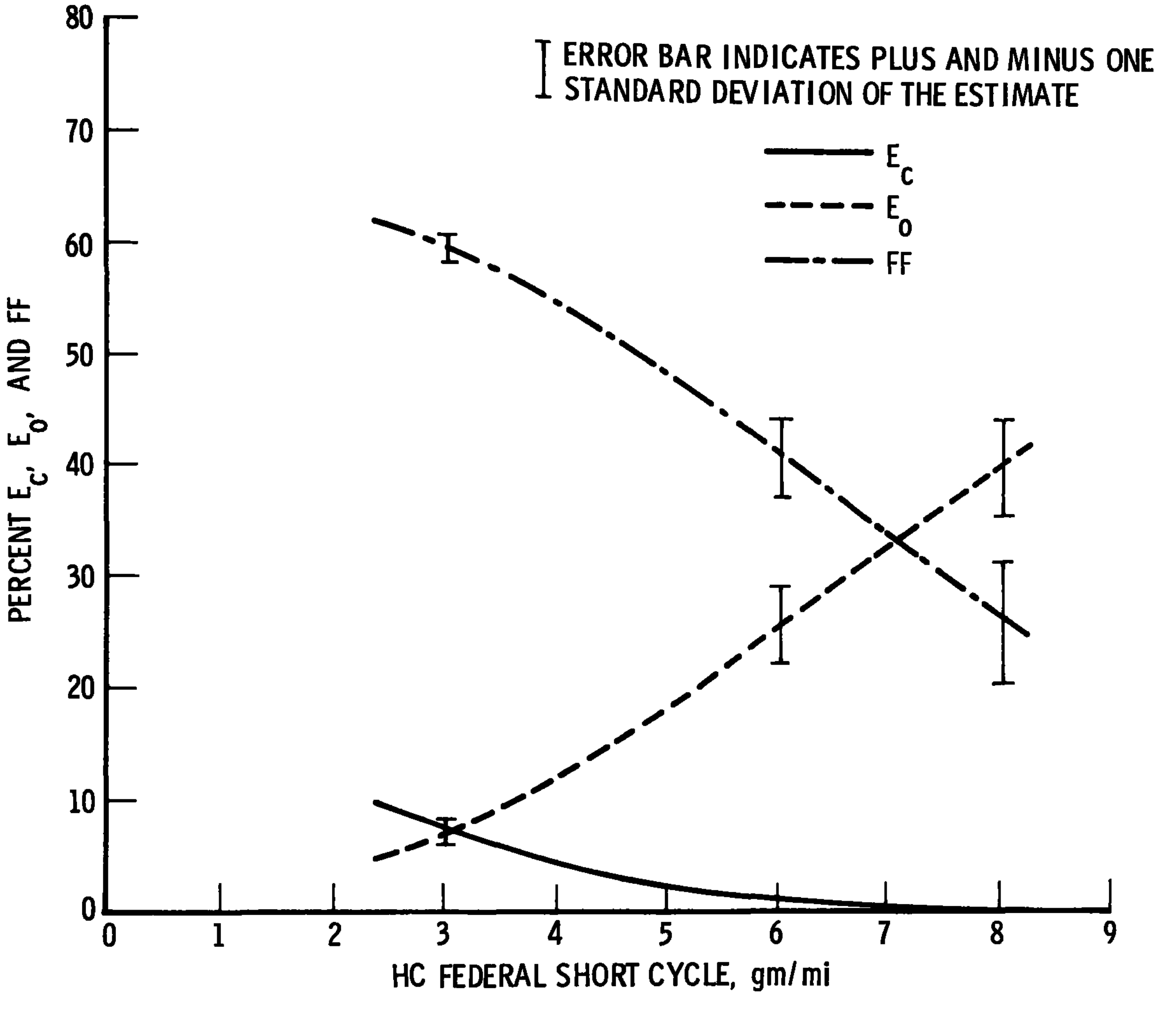


Figure 4-52. Variability of Predicted Population Results

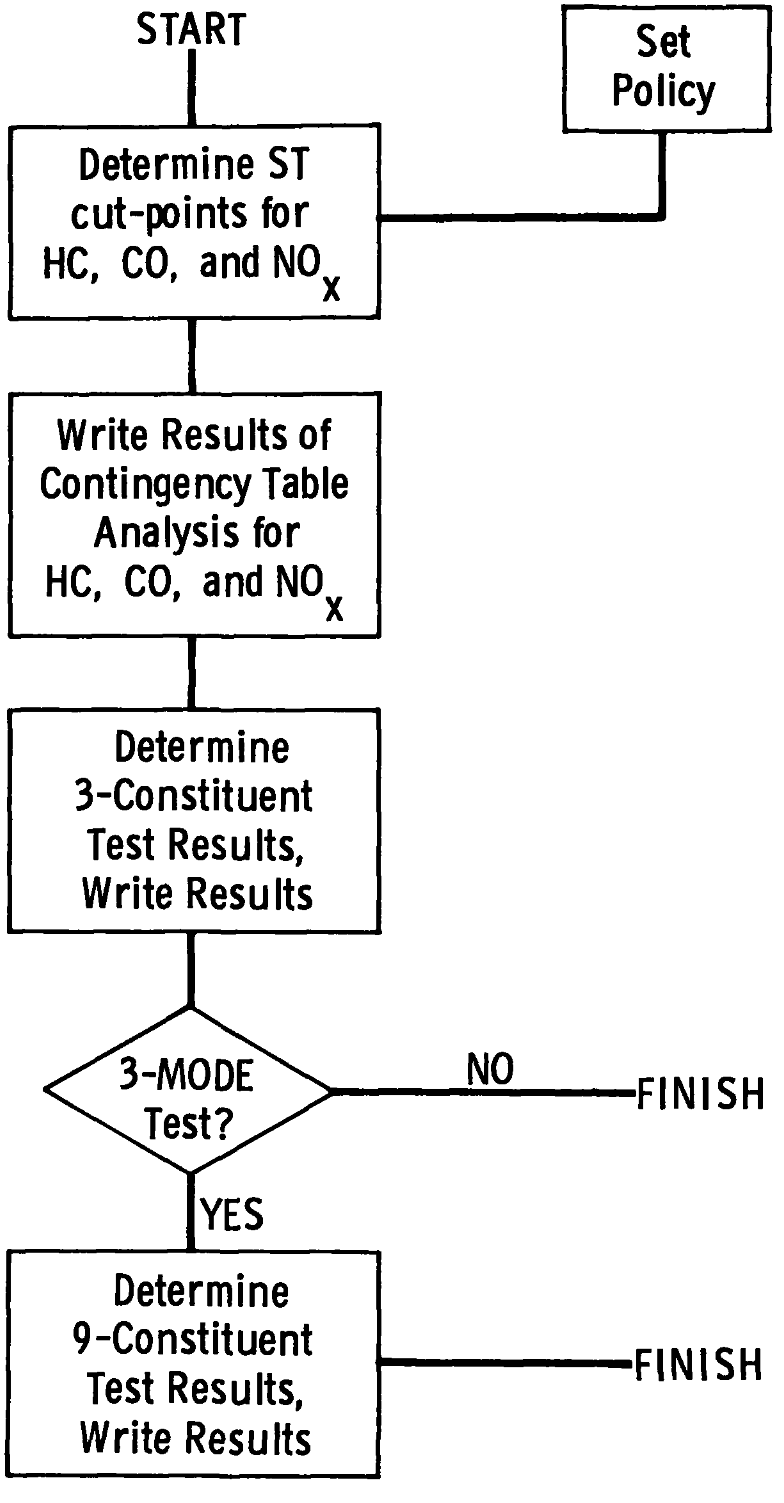


Figure 4-53. Computation Flow Chart

where FTP or ST failure occurs if any one of the test constituents exceeds its respective cut-points. A car is counted once in forming the table and falls into one, and only one, of the above categories. The percent E_c on a multiple-constituent test may be larger than the largest individual pollutant percent E_c, or may be smaller than the smallest individual pollutant percent E_c, depending upon the actual data set and its particular mix of pollutant failures. A useful observation, using the individual pollutant results, of the actual percent E_c for the multiple constituent test is

$$\text{Percent } E_c \simeq (\text{maximum pollutant ST percent FF}) \times (\text{minimum pollutant FTP percent PP})$$

Other useful relations for the multiple constituent tests are:

$$\text{Percent FF} \geq \max\,(\text{pollutant percent FF})$$

$$\text{Percent PP} \leq \min\,(\text{pollutant percent PP})$$

The three-constituent test results for the Federal Short Cycle and the Federal Three-Mode (high-speed and idle modes only) are summarized in Figures 4-54 through 4-65. The data plotted are the parametric population results. Both the laboratory and garage instrument results are displayed for the Federal Three-Mode short test (Figures 4-58 through 4-65).

The data were generated in the following manner: The method of bounded errors of commission was used to determine an ST pass/fail cut-point for each pollutant individually. The three-constituent test results were obtained by simultaneously comparing the observed emission levels for HC, CO, and NO_x of a vehicle against the determined ST and the given FTP cut-points.

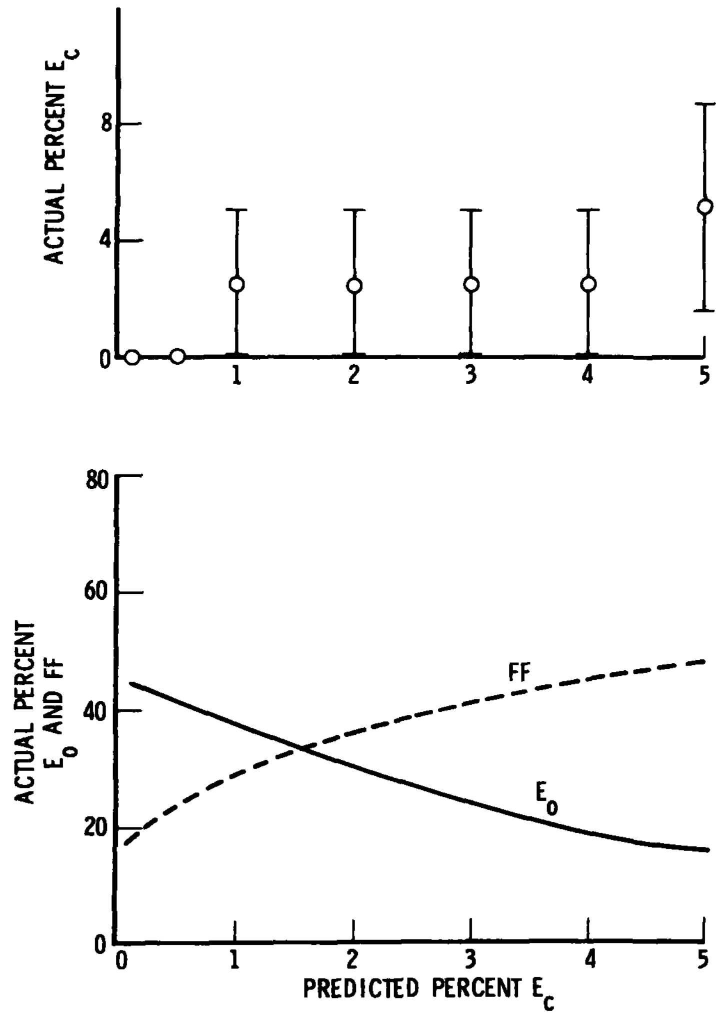


Figure 4-54. Variation of Actual E_C, E_O, and FF with Predicted E_C; Federal Short Cycle; Three-Constituent Test; Bounded Errors of Commission Method; CEV Fleet; 1975 FTP Level I

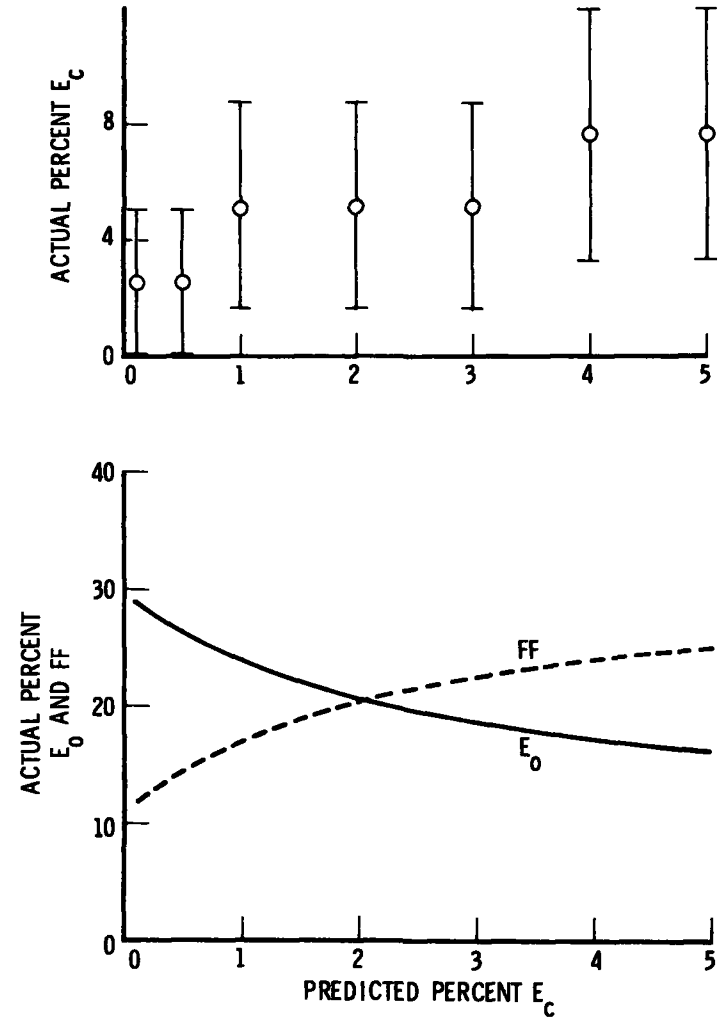


Figure 4-55. Variation of Actual E_C, E_O, and FF with Predicted E_C; Federal Short Cycle; Three-Constituent Test; Bounded Errors of Commission Method; CEV Fleet; 1975 FTP Level II

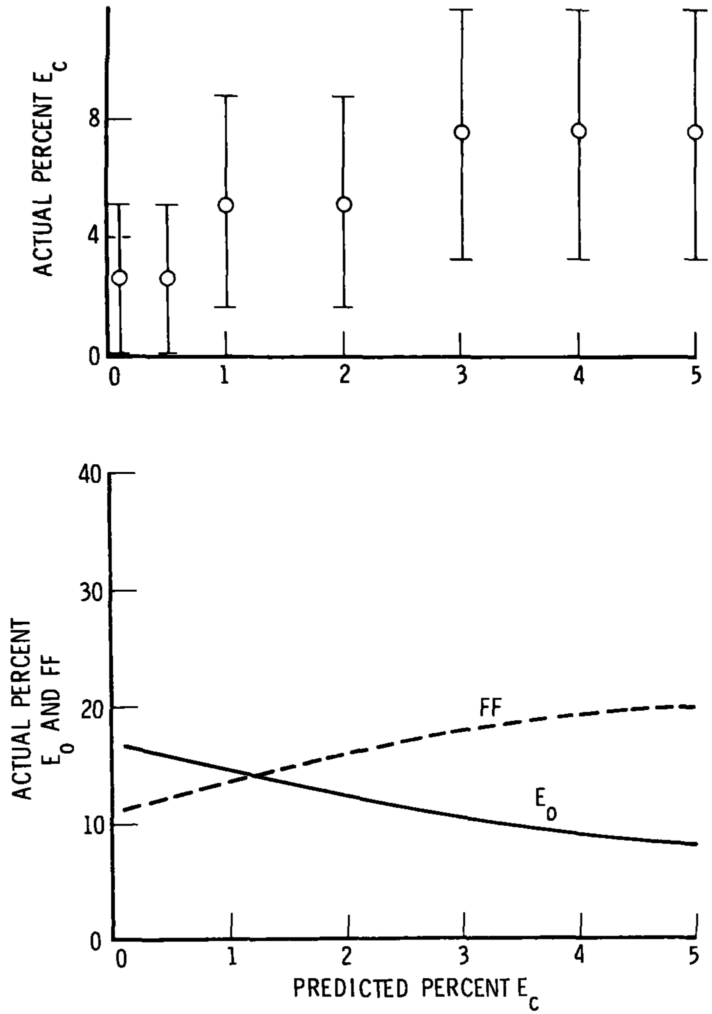


Figure 4-56. Variation of Actual E_c, E_o, and FF with Predicted E_c; Federal Short Cycle; Three-Constituent Test; Bounded Errors of Commission Method; CEV Fleet; 1975 FTP Level III

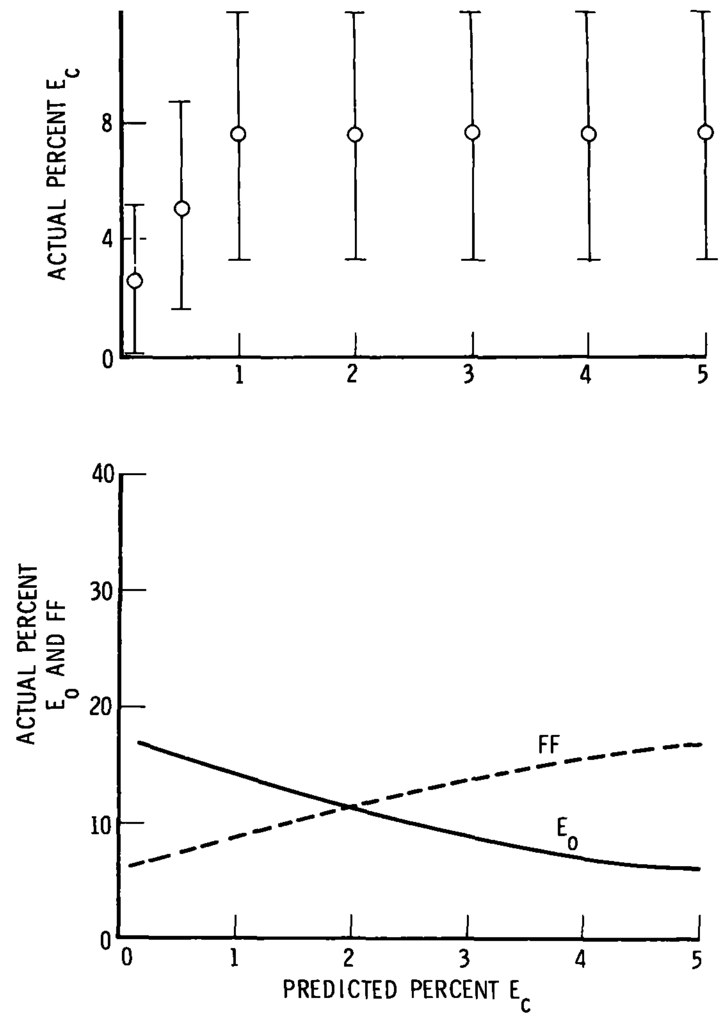


Figure 4-57. Variation of Actual E_c, E_o, and FF with Predicted E_c; Federal Short Cycle; Three-Constituent Test; Bounded Errors of Commission Method; CEV Fleet; 1975 FTP Level IV

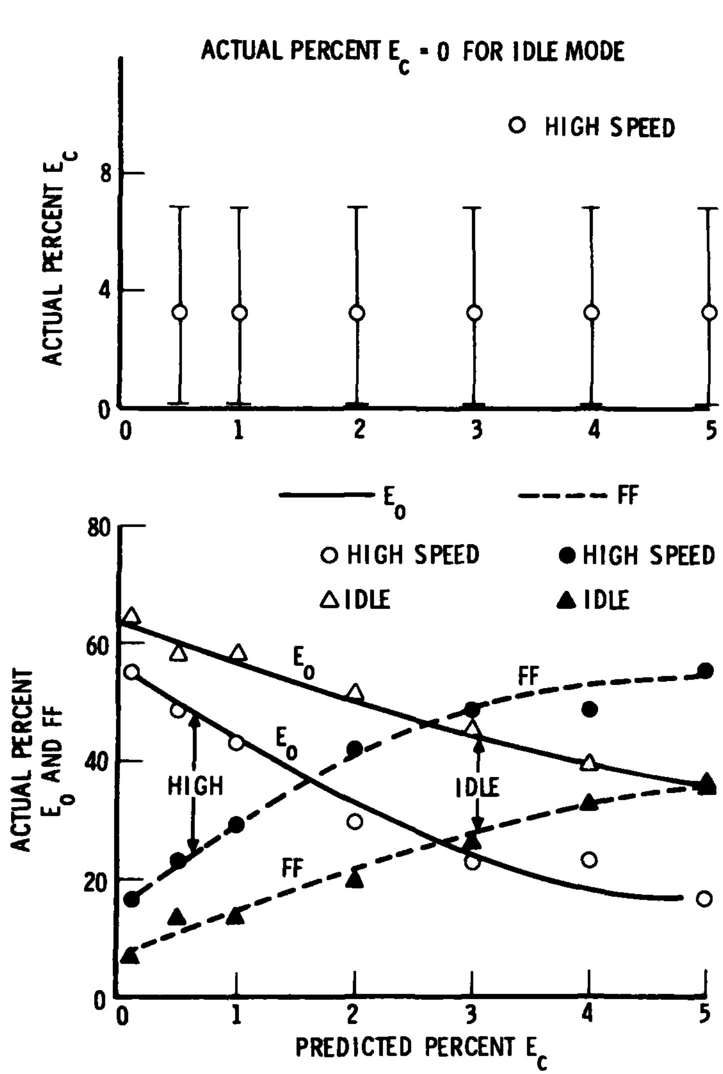


Figure 4-58. Variation of Actual E_c, E_o, and FF with Predicted E_c; Federal Three-Mode; Laboratory Instruments; Three-Constituent Test; Bounded Errors of Commission Method; CEV Fleet; 1975 FTP Level I

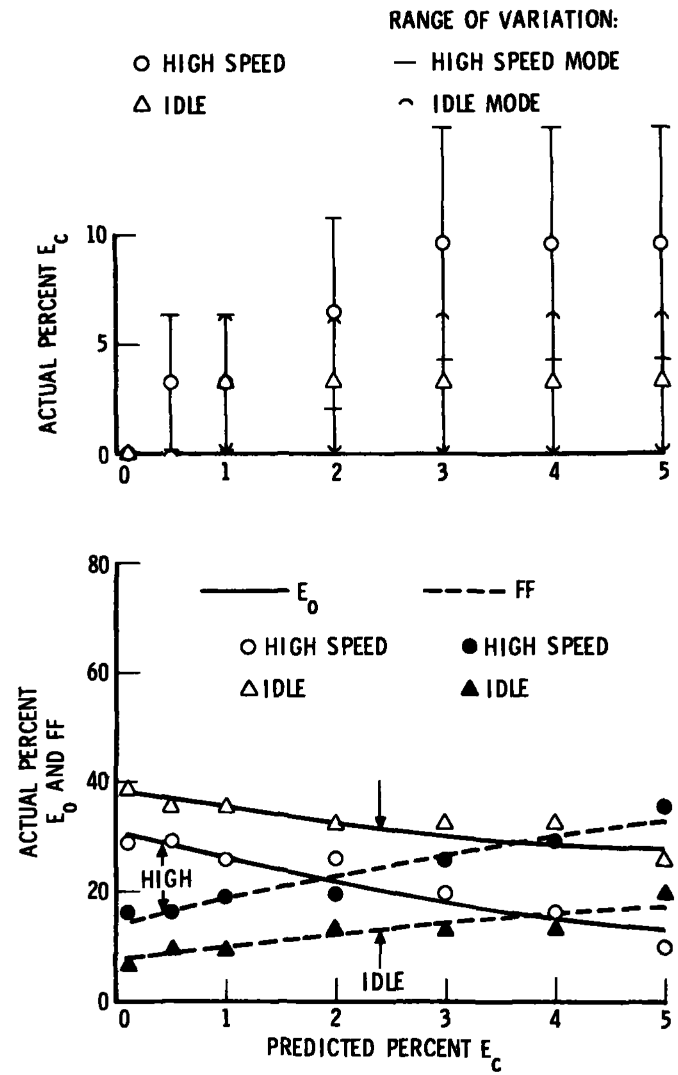


Figure 4-59. Variation of Actual E_c, E_o, and FF with Predicted E_c; Federal Three-Mode; Laboratory Instruments; Three-Constituent Test; Bounded Errors of Commission Method; CEV Fleet; 1975 FTP Level II

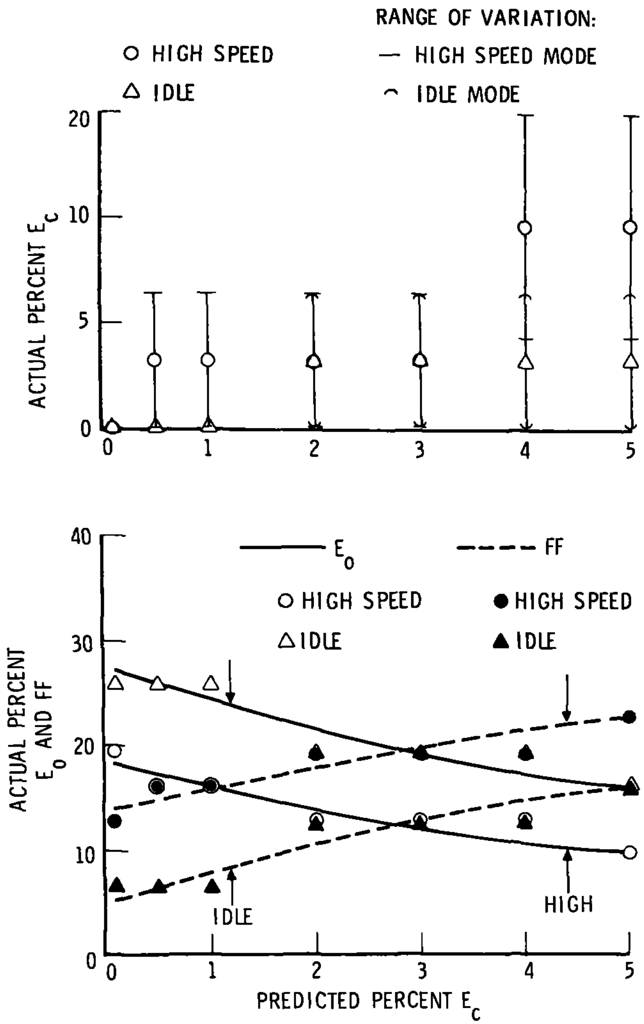


Figure 4-60. Variation of Actual E_c, E_o, and FF with Predicted E_c; Federal Three-Mode; Laboratory Instruments; Three-Constituent Test; Bounded Errors of Commission Method; CEV Fleet; 1975 FTP Level III

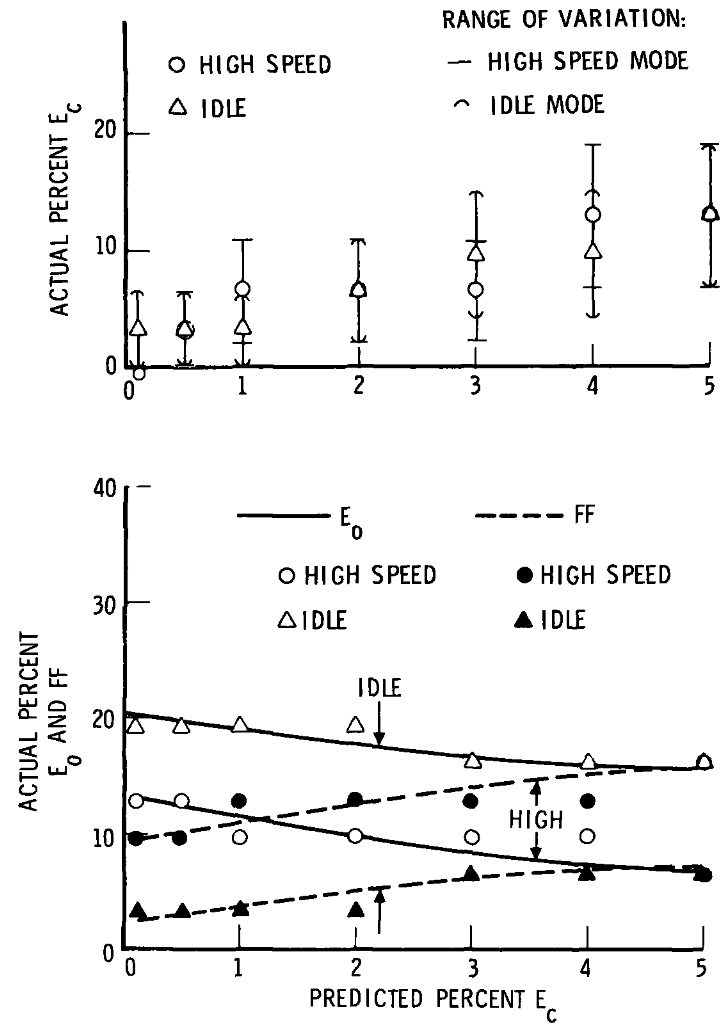


Figure 4-61. Variation of Actual E_c, E_o, and FF with Predicted E_c; Federal Three-Mode; Laboratory Instruments; Three-Constituent Test; Bounded Errors of Commission Method; CEV Fleet; 1975 FTP Level IV

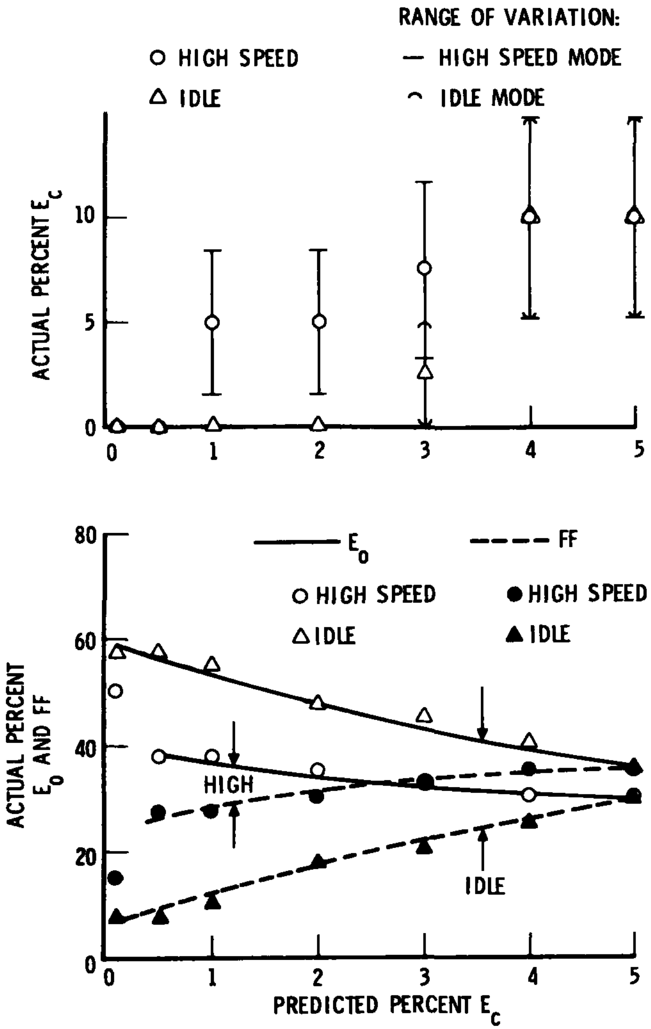


Figure 4-62. Variation of Actual E_C, E_O, and FF with Predicted E_C; Federal Three-Mode; Garage Instruments; Three-Constituent Test; Bounded Errors of Commission Method; CEV Fleet; 1975 FTP Level I

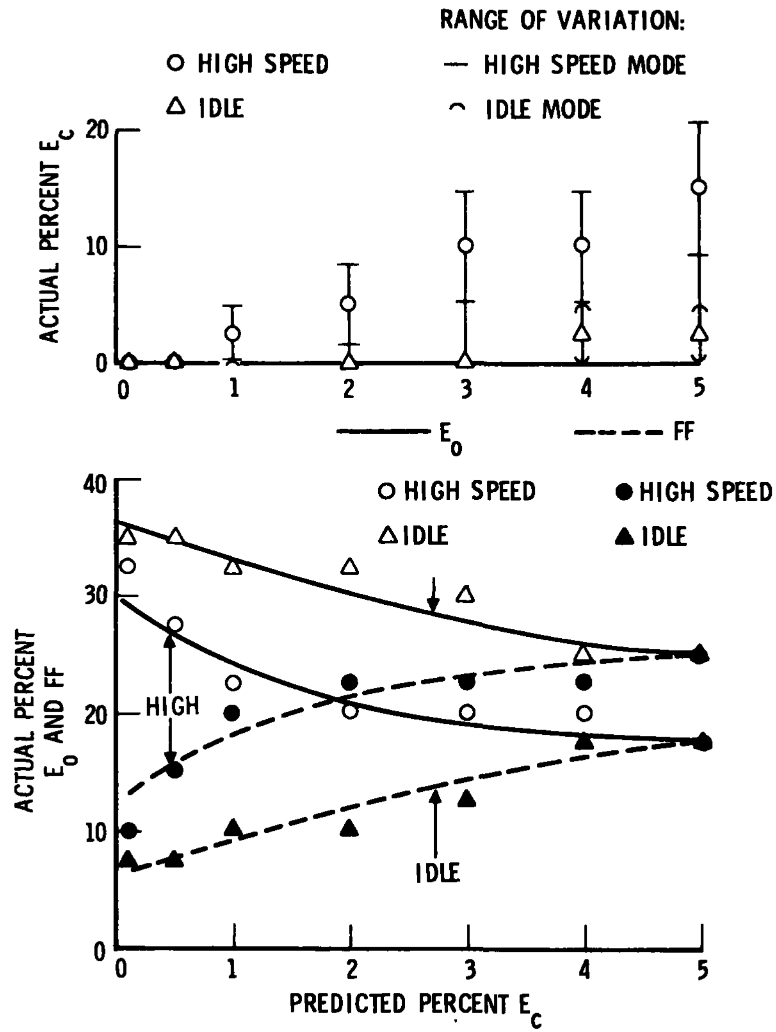


Figure 4-63. Variation of Actual E_C, E_O, and FF with Predicted E_C; Federal Three-Mode; Garage Instruments; Three-Constituent Test; Bounded Errors of Commission Method; CEV Fleet; 1975 FTP Level II

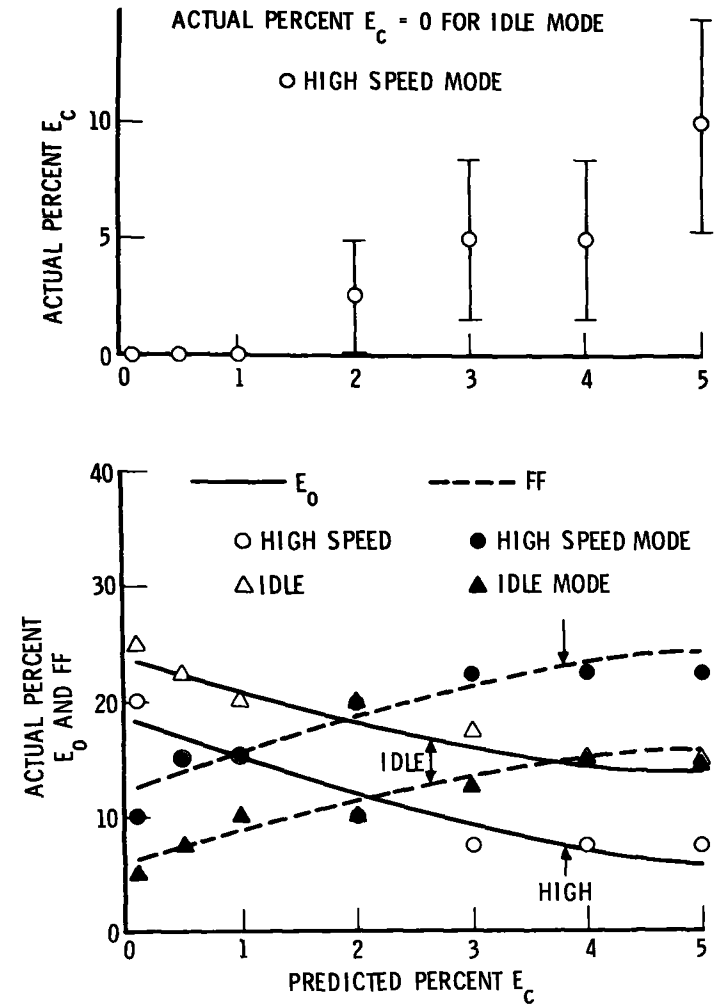


Figure 4-64. Variation of Actual E_c, E_o, and FF with Predicted E_c; Federal Three-Mode; Garage Instruments; Three-Constituent Test; Bounded Errors of Commission Method; CEV Fleet; 1975 FTP Level III

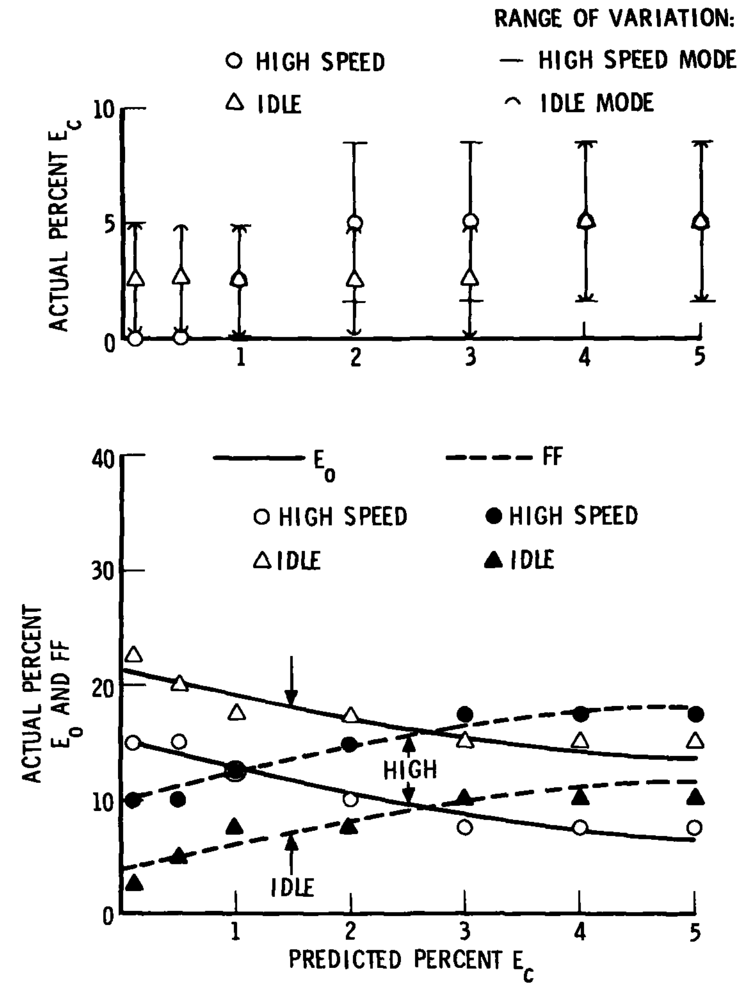


Figure 4-65. Variation of Actual E_c, E_o, and FF with Predicted E_c; Federal Three-Mode; Garage Instruments; Three-Constituent Test; Bounded Errors of Commission Method; CEV Fleet; 1975 FTP Level IV

The results in the figures are presented as follows: for each three-constituent test, the actual errors of omission, actual correct failures, and actual errors of commission are plotted versus the predicted error of commission that was the original bound on the individual pollutants. For example, in Figure 4-54, if policy was set at a maximum of 2 percent errors of commission on each individual pollutant, the actual results of a three-constituent test are about 30 percent errors of omission, 36 percent correct failures, and 2.6 percent errors of commission. For the actual errors of commission, plus or minus one standard error of the estimate is indicated by an error bar, with the value of the estimate in the center of the bar. In the above example, plus one standard error of the estimate gives about 5 percent E_c, while the minus side shows about 0.1 percent E_c, with the observed value being 2.6 percent E_c.

4.2.2.5.2.2 Variance Estimates

For fixed ST and FTP cut-points, the cell counts in a 2 × 2 contingency table are binomially distributed when the observations are independent (Ref. 4-6). Since the ST cut-points are computed from data prior to forming the contingency table, there is statistical dependence between the ST cut-points and the resulting table. Hence, the binomial distribution will be an approximation to the true distribution. Thus, the approximate standard deviation is

$$\sqrt{\frac{X (100 - X}{N}}$$

where

X = cell count in percent

N = total table count

For example, if the percent errors of omission is computed to be 50 percent, then, with 40 cars, the standard deviation is 7.9 percent. Table 4-21 shows the approximate cell standard deviations for the range of cell percentages assuming N = 40. This procedure was also used to calculate the standard error of the estimate depicted in Figures 4-54 through 4-65 by the error bars on the actual errors of commission.

4.2.2.5.2.3 Discussion of Results

As the FTP cut-points increase from level Set I to level Set IV, the resulting actual errors of commission tend to increase for a given predicted level of errors of commission. For example, on the Federal Short Cycle at 2 percent predicted errors of commission, the actual errors are 2.5 percent, 5 percent, 5 percent, and 7.5 percent for FTP levels I, II, III, and IV, respectively. This trend is not present for the garage instrument results as shown in Figures 4-62 through 4-65.

Table 4-21. Approximate Standard Deviation for Three-Constituent Tests - CEV Fleet, N = 40

Cell Percentage	Cell Standard Deviation, %
60	7.75
50	7.91
40	7.75
30	7.25
20	6.32
12.5[a]	5.23
10[b]	4.74
5[b]	3.45

[a] Cell count equal 5

[b] Cell count less than 5; actual standard deviations may be significantly higher or lower than values shown due to small sample size effects

A comparison of the modes on the Federal Three-Mode test shows that, for a fixed predicted percent E_c, the high speed mode has a higher percent FF and lower percent E_o than does the idle mode. This is true regardless of instrumentation or FTP level. However, the actual percent E_c is generally lower on the idle mode than on the high-speed mode, but this difference is not always significant.

A comparison of different modes or ST should be made on a fixed actual percent E_c basis. This is, of course, difficult to do because of the computational procedure followed. It can be approximately performed, however. Consider comparing the Federal Short Cycle to the Federal Three-Mode. At FTP level I, the actual percentages of E_c are approximately the same for the high speed mode and the Federal Short Cycle (statistically, they are equivalent). Now, comparing the percent FF and percent E_o curves, percent FF and percent E_o are both higher on the high-speed mode than the Federal Short Cycle. This difference is not statistically significant at the 95 percent level, and the two tests would have to be judged as equal. Also, at the 95 percent level, the high-speed mode is superior to the idle mode.

The differences between laboratory and garage instruments are quite predictable, based upon the previous results from individual pollutants. For a fixed predicted percent E_c, on their respective modes,

a. Actual percent E_c is higher for garage instruments than for laboratory instruments

b. Actual percent FF is lower for garage instruments than for laboratory instruments

c. Actual percent E_o is higher for garage instruments than for laboratory instruments.

4.3 REFERENCES FOR SECTION 4

The following references are used in Section 4:

4-1. W. J. Dixon, ed., BMPD Biomedical Computer Program, University of California Press, Berkeley (1974).

4-2. D. F. Morrison, Multivariate Statistical Methods, McGraw-Hill Book Co., Inc., New York (1967).

4-3. F. A. Graybill, An Introduction to Linear Statistical Models, Vol. 1, McGraw-Hill Book Col, Inc., New York (1961).

4-4. T. W. Anderson, Multivariate Statistical Analysis, John Wiley and Sons, Inc., New York (1958).

4-5. H. Cramer, Mathematical Methods of Statistics, Princeton University Press, New Jersey (1971).

4-6. C. R. Rao, Linear Statistical Inference and Its Applications, John Wiley and Sons, Inc., New York (1965).

5. IN-USE 1974 MODEL YEAR VEHICLE FLEET

5. IN-USE 1974 MODEL YEAR VEHICLE FLEET

This section summarizes the results of statistical analyses conducted to determine the degree of correlation existing between the various short tests (STs) and FTP tests conducted on a fleet of in-use 1974 model year vehicles.

Several distinguishing features of the 1974 model year fleet resulted in variations in focus and scope of the statistical analyses from those reported for the CEV fleet in Section 4. They include:

a. The 1974 model year fleet was manufactured to known emission standard values, whereas the CEV fleet was not.

b. The 1974 model year fleet population was stratified by three inertia test weight groups, whereas the CEV fleet was at a single inertia test weight value.

c. There was no substantial number of replicate test observations for the 1974 model year fleet.

The appropriate 1975 FTP emission standards for the 1974 model year fleet were computed to be:

$HC = 3.02$ gm/mi

$CO = 28.0$ gm/mi

$NO_x = 3.1$ gm/mi

The three inertia test weight groups were designated as:

Group A (4000-lb class)

Group B (2750-lb class)

Group C (5500-lb class)

For analysis purposes, laboratory instrument test data were available for 147 cars, while garage-type instrument data were available for 144 cars. These test data had been processed by EPA and were received stored on magnetic tape. Correlation analysis results are summarized in Sec. 5.1; the contingency table analysis results are summarized in Sec. 5.2.

5.1 CORRELATION ANALYSIS RESULTS

A conventional correlation analysis was made for the 1974 model year fleet. The method was as described in Sec. 4.2.1.1. The resulting ST/FTP correlation coefficients are summarized in Table 5-1 for the individual inertia test weight groups (A, B, C) and for the pooled vehicle population (combined groups A, B, C). For N = 147 cars, a computed correlation coefficient greater than 0.16 indicates that the ST and FTP pollutants are statistically correlated with 95% confidence. For N = 48 to 50, this threshold is approximately 0.29.

In addition, a correlation analysis of FTP composite emissions versus FTP bags 2 and 3 was made (by the method outlined in Sec. 4.2.1.1.1). The results are shown in Table 5-2.

As can be seen in Table 5-1, no single ST performs consistently well on all three individual groups, or on a pooled basis. Generally, the STs are unable to track HC and CO emission levels on Group C (5500-lb Chevrolet vehicles). This is also supported by the FTP composite versus bags 2 plus 3 correlations of Table 5-2. The low correlation for NO_x in Group C in Table 5-2 is the result of a single outlying point and, thus, does reflect an usually low relatability. However, the HC and CO correlations for Group C are significantly different (in the sense of a rigorous statistical test) than those of Groups A and B. This would indicate that "hot" procedures would not perform as well on Group C as on Groups A and B.

The presence of one ST with good NO_x correlation across the population is missing in the 1974 model year fleet. From a correlation viewpoint, the garage analyzers are inferior to the laboratory analyzers. ST ratings using the scale established in Sec. 4.2.1.4.4 for the CEV fleet are given in Table 5-3. As with the CEV fleet (Table 4-8), the bag-type STs have higher ratings than the volumetric tests. The 2500 rpm Unloaded test shows substantially higher correlation for the 1974 model year fleet than for the CEV fleet. The extreme CO tracking deficiency for the CEV fleet data is not evident for the 1974 model year fleet.

Table 5-1. Correlation Coefficient Summary: 1974 Model Year Fleet

Short Test	Vehicle Group[a]	Test Mode	N[b]	ST/FTP Correlation Coefficient[c]		
				HC	CO	NO_x
Federal Short Cycle	Pooled		147	0.932	0.905	0.355
	A		50	0.933	0.972	0.780
	B		48	0.897	0.897	0.104*
	C		49	0.383	0.476	0.674
NY/NJ Composite	Pooled		147	0.906	0.890	0.060*
	A		50	0.911	0.950	0.733
	B		48	0.920	0.857	0.005*
	C		49	0.513	0.498	0.611
Key Mode (Laboratory)	Pooled	High	147	0.757	0.518	0.521
		Low		0.776	0.769	0.419
		Idle		0.793	0.739	0.463
	A	High	50	0.590	0.514	0.562
		Low		0.595	0.827	0.495
		Idle		0.723	0.704	0.381
	B	High	48	0.812	0.262*	0.731
		Low		0.868	0.738	0.635
		Idle		0.825	0.650	0.548
	C	High	49	0.238*	-0.195*	0.555
		Low		0.228*	0.435	0.580
		Idle		0.460	0.757	0.571
Key Mode (Garage)	Pooled	High	145	0.528	0.507	
		Low		0.545	0.472	
		Idle		0.455	0.470	
	A	High	50	0.228*	0.563	
		Low		0.151*	0.652	
		Idle		0.245*	0.372	

Table 5-1. Correlation Coefficient Summary: 1974 Model Year Fleet (Continued)

Short Test	Vehicle Group[a]	Test Mode	N[b]	ST/FTP Correlation Coefficient[c]		
				HC	CO	NO_x
	B	High	46	0.478	0.362	
		Low		0.765	0.540	
		Idle		0.692	0.560	
	C	High	49	0.191*	-0.221*	
		Low		0.198*	-0.091*	
		Idle		0.100*	0.229*	
Federal Three-Mode (Laboratory)	Pooled	High	147	0.766	0.604	0.467
		Low		0.771	0.729	0.453
		Idle		0.803	0.734	0.411
	A	High	50	0.507	0.717	0.492
		Low		0.523	0.801	0.664
		Idle		0.709	0.724	0.369
	B	High	48	0.890	0.278*	0.722
		Low		0.859	0.737	0.611
		Idle		0.851	0.622	0.665
	C	High	49	0.522	0.159*	0.552
		Low		0.533	0.592	0.707
		Idle		0.252*	0.733	0.639
Federal Three-Mode (Garage)	Pooled	High	145	0.474	0.387	
		Low		0.531	0.409	
		Idle		0.632	0.476	
	A	High	50	0.138*	0.533	
		Low		0.107*	0.597	
		Idle		0.660	0.397	

Table 5-1. Correlation Coefficient Summary: 1974 Model Year Fleet (Continued)

Short Test	Vehicle Group[a]	Test Mode	N[b]	ST/FTP Correlation Coefficient[c]		
				HC	CO	NO_x
	B	High	46	0.536	0.268*	
		Low		0.763	0.539	
		Idle		0.717	0.550	
	C	High	49	0.095*	-0.083*	
		Low		-0.008*	0.239*	
		Idle		-0.060*	0.392	
2500 rpm Unloaded (Laboratory)	Pooled		147	0.809	0.740	0.447
	A		50	0.832	0.812	0.524
	B		48	0.865	0.724	0.577
	C		49	0.107*	0.350	0.679
2500 rpm Unloaded (Garage)	Pooled		147	0.574	0.447	
	A		50	0.487	0.676	
	B		46	0.781	0.684	
	C		49	-0.064*	-0.051*	

[a] A = Chrysler (4000 lb)
B = Ford (2750 lb)
C = Chevrolet (5500 lb)
Pooled = Groups A + B + C

[b] Number of cars in the data set

[c] The correlations are statistically significant at the 95 percent confidence level except where indicated by an asterisk. ST and FTP uncorrelated for correlations below 0.28.

Table 5-2. FTP Composite Versus Bag 2 + 3 Correlation Coefficients: 1974 Model Year Fleet

Vehicle Group	N[a]	FTP/FTP Bag 2 + 3 Correlation Coefficient[b]		
		HC	CO	NO_x
Pooled	147	0.992	0.994	0.925
A	50	0.987	0.993	0.976
B	48	0.998	0.996	0.996
C	49	0.965	0.987	0.761

[a] Number of cars in data set

[b] The correlations are statistically significant at the 95% confidence level

Table 5-3. ST Ratings: 1974 Model Year Fleet

Short Test	Vehicle Group[a]	Ratings[b]		
		HC	CO	NO_x
Federal Short Cycle	Pooled	E	E	P
	A	E	E	G
	B	G	E	U
	C	P	P	F
NY/NJ Composite	Pooled	E	G	U
	A	E	E	G
	B	E	G	U
	C	P	P	F
Key Mode (Laboratory)	Pooled	G (I)[c]	G (L)	P (H)
	A	G (I)	G (L)	P (H)
	B	G (L)	G (L)	G (H)
	C	P (I)	G (I)	P (L)
Key Mode (Garage)	Pooled	P (L)	P (H)	
	A	U	F (L)	
	B	G (L)	P (L)	
	C	U	U	
Federal Three-Mode (Laboratory)	Pooled	G (I)	G (I)	P (H)
	A	G (I)	G (L)	F (L)
	B	G (H)	G (I)	G (H)
	C	P (L)	G (I)	G (L)
Federal Three-Mode (Garage)	Pooled	F (I)	P (I)	
	A	F (I)	P (L)	
	B	G (L)	P (I)	
	C	U	P (I)	

Table 5-3. ST Ratings: 1974 Model Year Fleet (Continued)

Short Test	Vehicle Group[a]	Ratings[b]		
		HC	CO	NO_x
2500 rpm Unloaded (Laboratory)	Pooled	G	G	P
	A	G	G	P
	B	G	G	P
	C	U	P	F
2500 rpm Unloaded (Garage)	Pooled	P	P	
	A	P	F	
	B	G	F	
	C	U	U	

[a] A = Chrysler (4000 lb)
B = Ford (2750 lb)
C = Chevrolet (5500 lb)
Pooled = Groups A + B + C

[b] Rating scale as in Sec. 1.1.1.8

[c] I = idle
L = low speed mode
H = high speed mode

5.2 CONTINGENCY TABLE ANALYSIS RESULTS

5.2.1 Maximum Correlation Method

Using the method as defined in Sec. 4.2.2.1, a maximum correlation analysis was made for the pooled sample population of the 1974 model year fleet. Table 5-4 summarizes the analysis results for the predicted population. For N = 147, a computed table correlation coefficient greater than 0.16 indicates that the ST and FTP pollutants are statistically correlated with 95% confidence.

Examination of these results indicates that the correlation indices (Table 5-4) are quite similar to the relative ST ratings developed in Table 5-3. NO_x tracking difficulty is indicated by a high percentage of E_c relative to percent FF. CO is the dominant variable in that it has the highest percent FTP failure rate. (For the CEV fleet, the dominant variable was HC.)

5.2.2 Bounded Errors of Commission Method

A contingency table analysis for the 1974 model year fleet was made using the methods described in Sec. 4.2.2.1.2 and 4.2.2.2. For this analysis the bound on percent E_c was varied from 5 percent to 1 percent in 1 percent increments, with the values 0.5 percent and 0.1 percent included. The results of the analysis are summarized below. The data shown are for the predicted 1974 model year fleet population.

5.2.2.1 Single-Constituent Tests

5.2.2.1.1 Hydrocarbon Emission

The variations of E_o, E_c, and FF as a function of HC cut-point are shown in Figures 5-1 through 5-8 for each ST examined. The graphical displays indicate the general nature of the tradeoffs available for policy formulation. Reducing the errors of commission (E_c) increases the errors of omission (E_o) and decreases the correct failures (FF). To illustrate specific values and trends among the STs, Table 5-5 summarizes data from the figures for the E_c value of 5 percent.

Table 5-4. Maximum Correlation Summary; 1974 Model Year Fleet, Predicted Population

ST	N	Test Mode	Pollutant	% E_c	% E_o	% FF	Table Correlation Index[a]
Federal Short Cycle	147		HC	6.05	5.44	35.4	0.763
			CO	5.02	6.94	65.5	0.708
			NO_x	26.8	7.56	10.5	0.201
NY/NJ Composite	147		HC	7.20	6.36	34.5	0.720
			CO	5.37	7.60	64.8	0.684
			NO_x	38.56	8.77	9.24	0.033*
Key Mode (Laboratory)	147	High speed	HC	12.2	10.0	30.8	0.544
			CO	9.99	20.3	52.1	0.330
			NO_x	20.4	6.77	11.24	0.310
		Low speed	HC	11.7	9.64	31.2	0.563
			CO	7.35	12.13	60.3	0.641
		Idle	HC	11.17	9.29	31.5	0.580
			CO	7.74	13.16	59.3	0.511
			NO_x	22.63	7.06	10.9	0.270
Key Mode (Garage)	144	High speed	HC	18.1	13.9	27.2	0.351
			CO	10.1	20.6	51.7	0.322
		Low speed	HC	17.4	13.5	27.6	0.371
			CO	10.4	21.7	50.62	0.297
		Idle	HC	19.4	14.8	26.3	0.305
			CO	10.4	21.7	50.7	0.298
Federal Three-Mode (Laboratory)	147	High speed	HC	11.9	9.83	31.0	0.553
			CO	9.20	17.5	54.8	0.394
			NO_x	22.5	7.04	11.0	0.273
		Low speed	HC	11.8	9.74	31.1	0.558
			CO	7.86	13.5	58.9	0.502
			NO_x	23.0	7.11	10.9	0.263
		Idle	HC	6.80	4.08	28.6	0.759
			CO	7.80	13.33	59.1	0.506
			NO_x	24.6	7.31	10.70	0.236
Federal Three-Mode (Garage)	144	High speed	HC	18.9	14.4	26.7	0.326
			CO	11.1	24.3	48.0	0.239
		Low speed	HC	17.7	13.7	27.41	0.363
			CO	10.9	23.7	48.7	0.254
		Idle	HC	12.2	15.4	28.9	0.437
			CO	10.3	21.4	50.9	0.303
2500-rpm Unloaded (Laboratory)	147		HC	10.7	8.94	31.9	0.597
			CO	7.72	13.1	59.3	0.513
			NO_x	23.3	7.14	10.9	0.259
2500-rpm Unloaded (Garage)	144		HC	16.5	12.9	28.2	0.402
			CO	10.6	22.3	50.0	0.283

[a] The correlation is statistically significant at the 95% confidence level except where indicated by an asterisk.

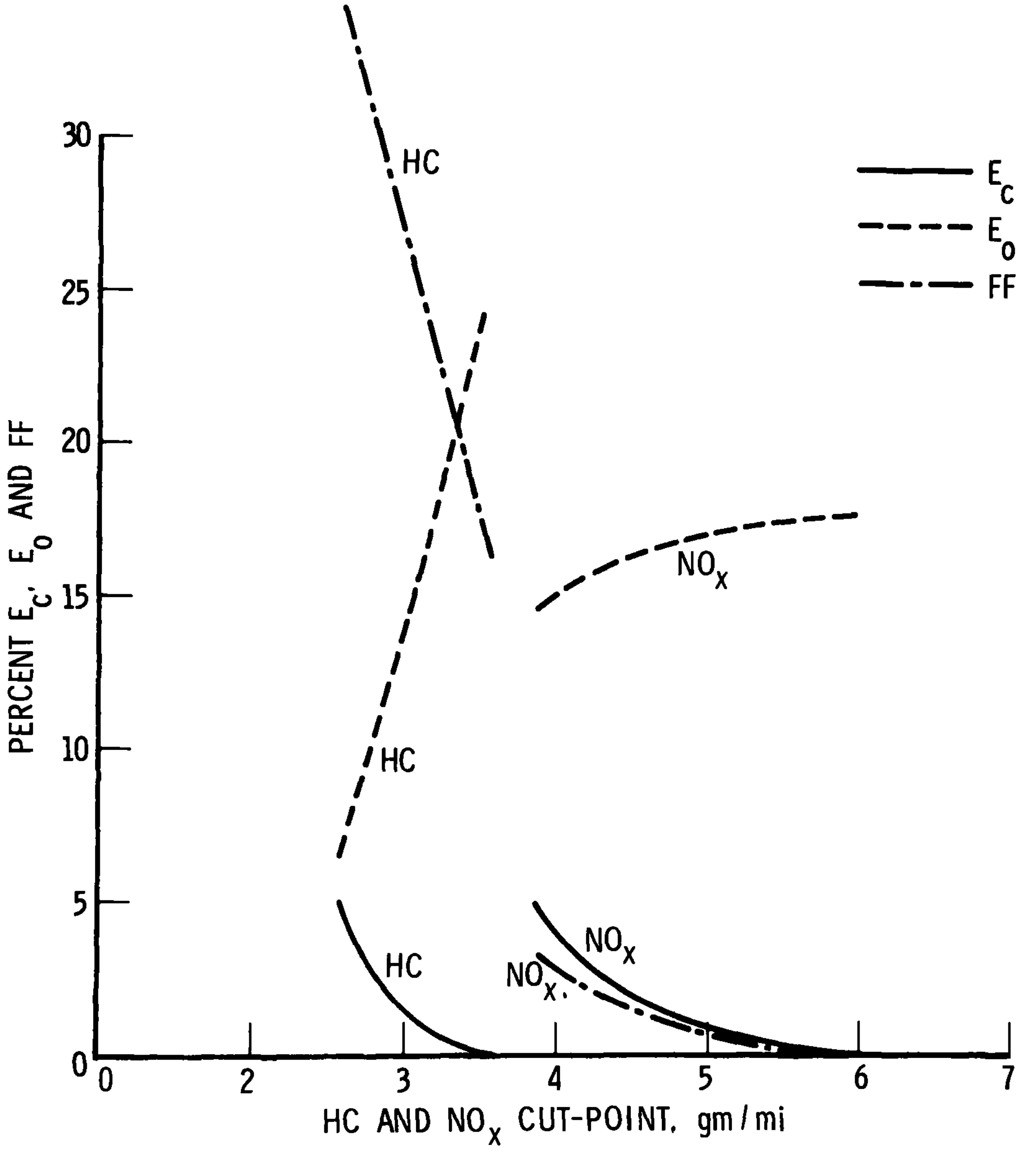


Figure 5-1. Variation of E_c, E_o, and FF with HC and NO_x Cut-Point; 1974 Model Year Fleet; Federal Short Cycle Test; Bounded Errors of Commission Method

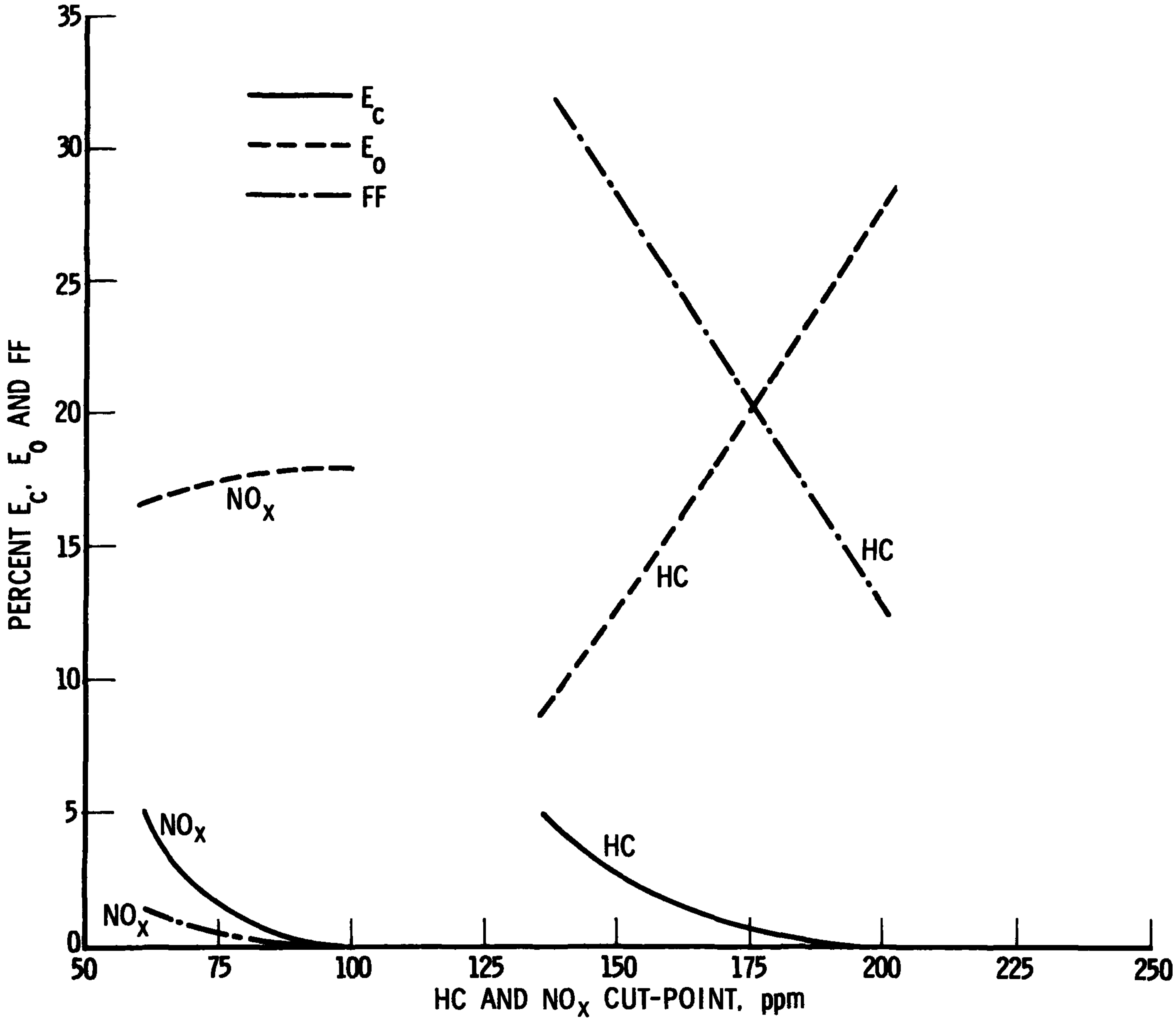


Figure 5-2. Variation of E_c, E_o, and FF with HC and NO_x Cut-Point; 1974 Model Year Fleet; NY/NJ Composite Test; Bounded Errors of Commission Method

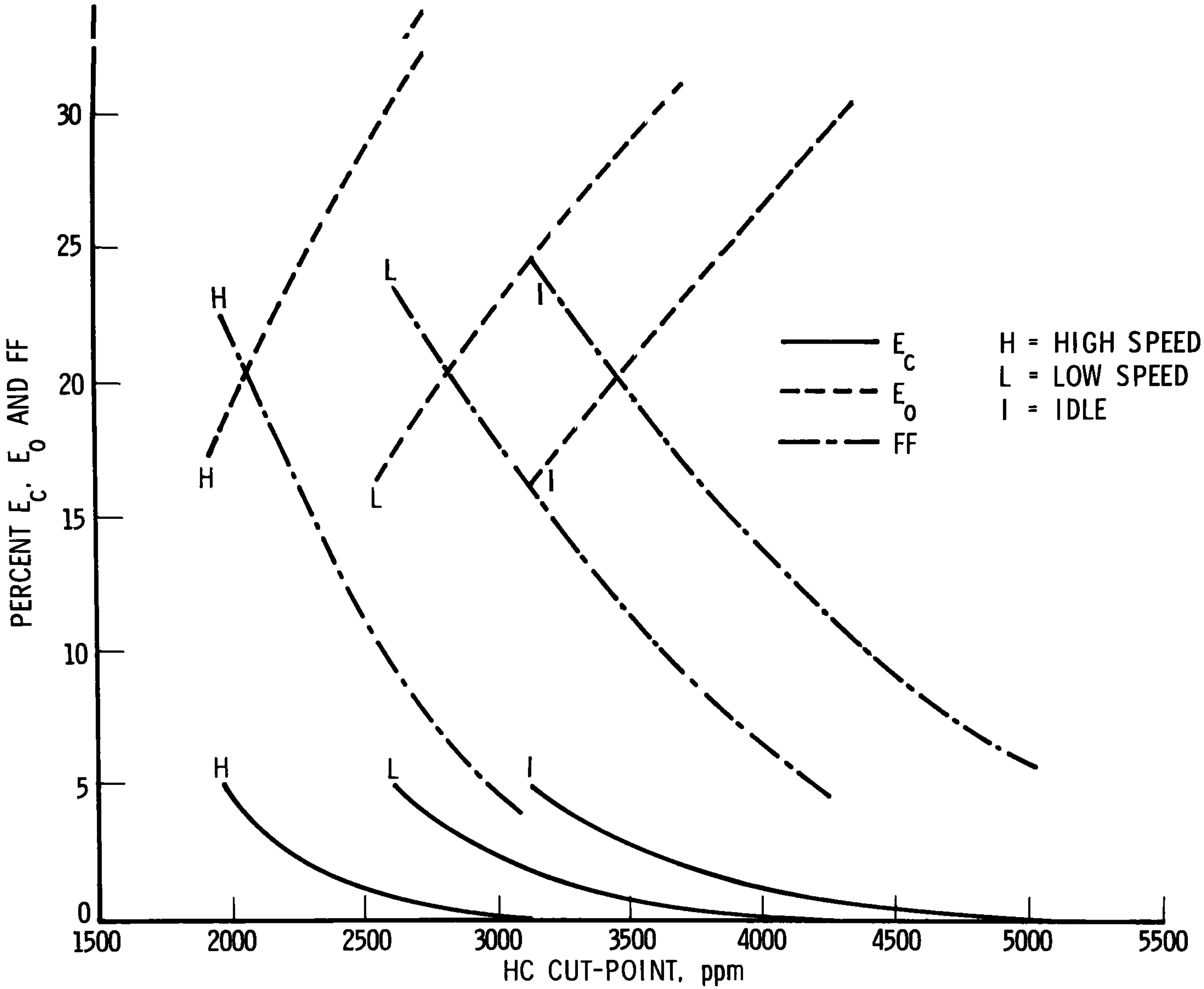


Figure 5-3. Variation of E_c, E_o, and FF with HC Cut-Point; 1974 Model Year Fleet; Key Mode Test; Bounded Errors of Commission Method

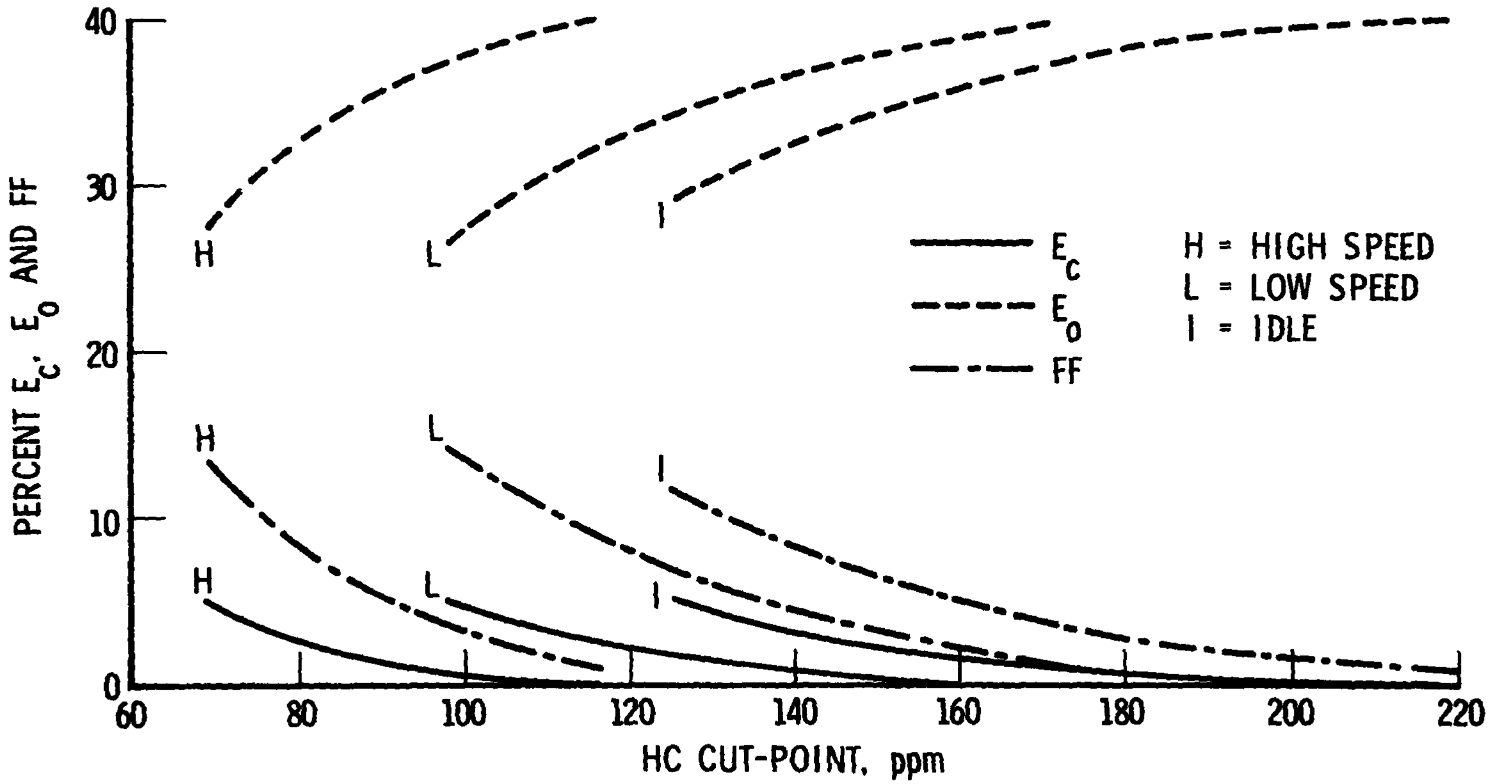


Figure 5-4. Variation of E_C, E_O, and FF with HC Cut-Point; 1974 Model Year Fleet; Key Mode Test; Garage Instruments; Bounded Errors of Commission Method

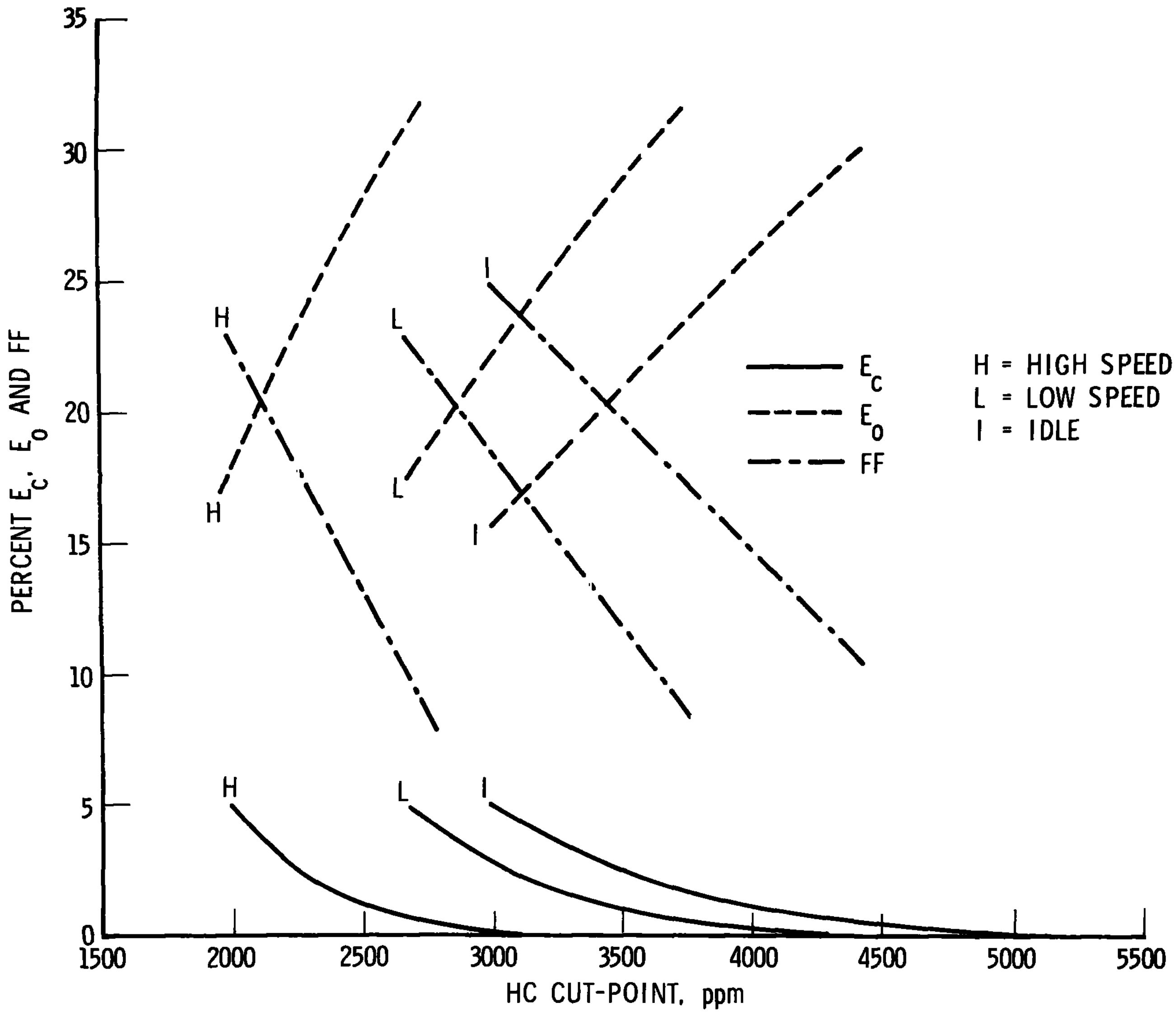


Figure 5-5. Variation of E_c, E_o, and FF with HC Cut-Point; 1974 Model Year Fleet; Federal Three-Mode Test; Bounded Errors of Commission Method

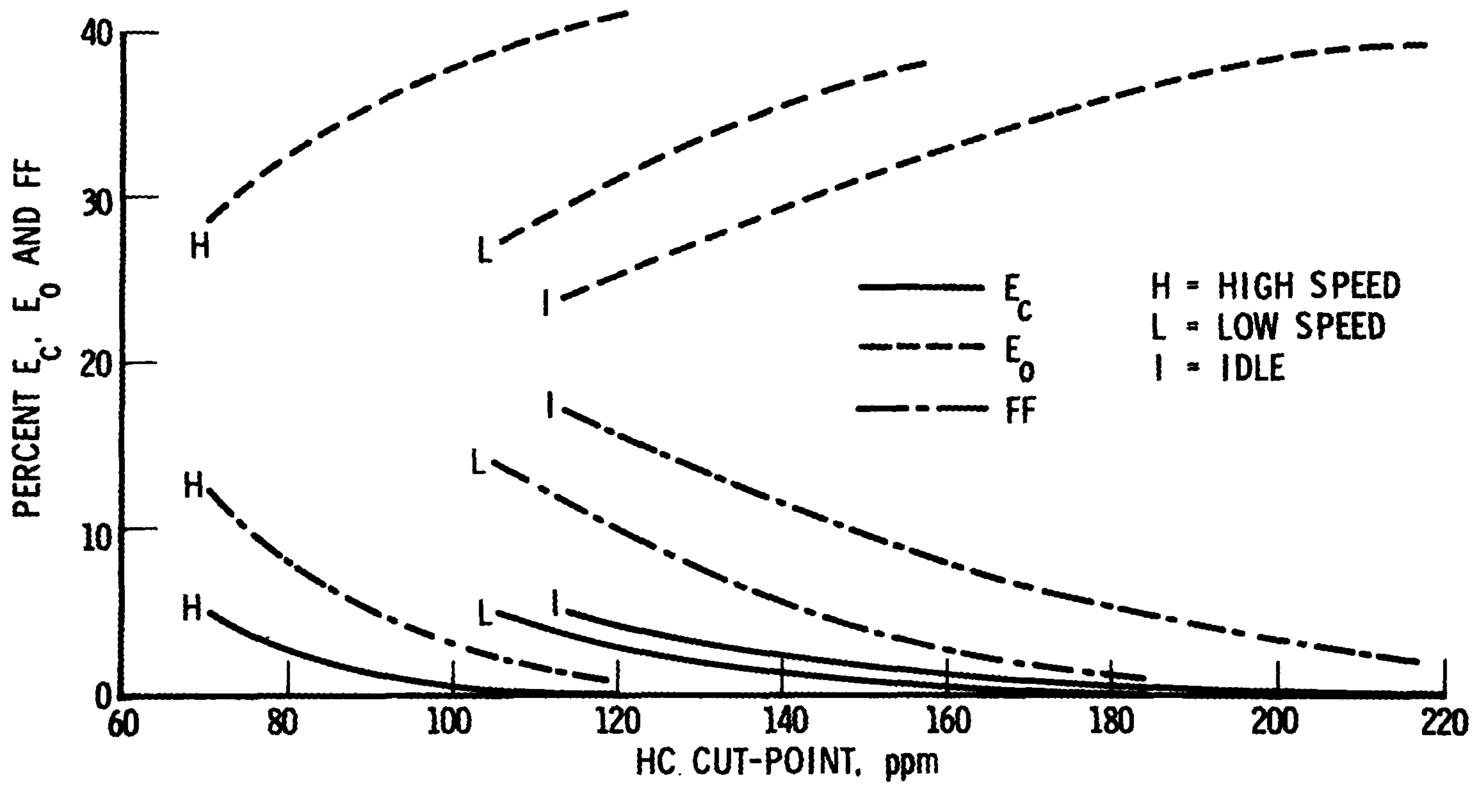


Figure 5-6. Variation of E_c, E_o, and FF with HC Cut-Point; 1974 Model Year Fleet; Federal Three-Mode Test; Garage Instruments; Bounded Errors of Commission Method

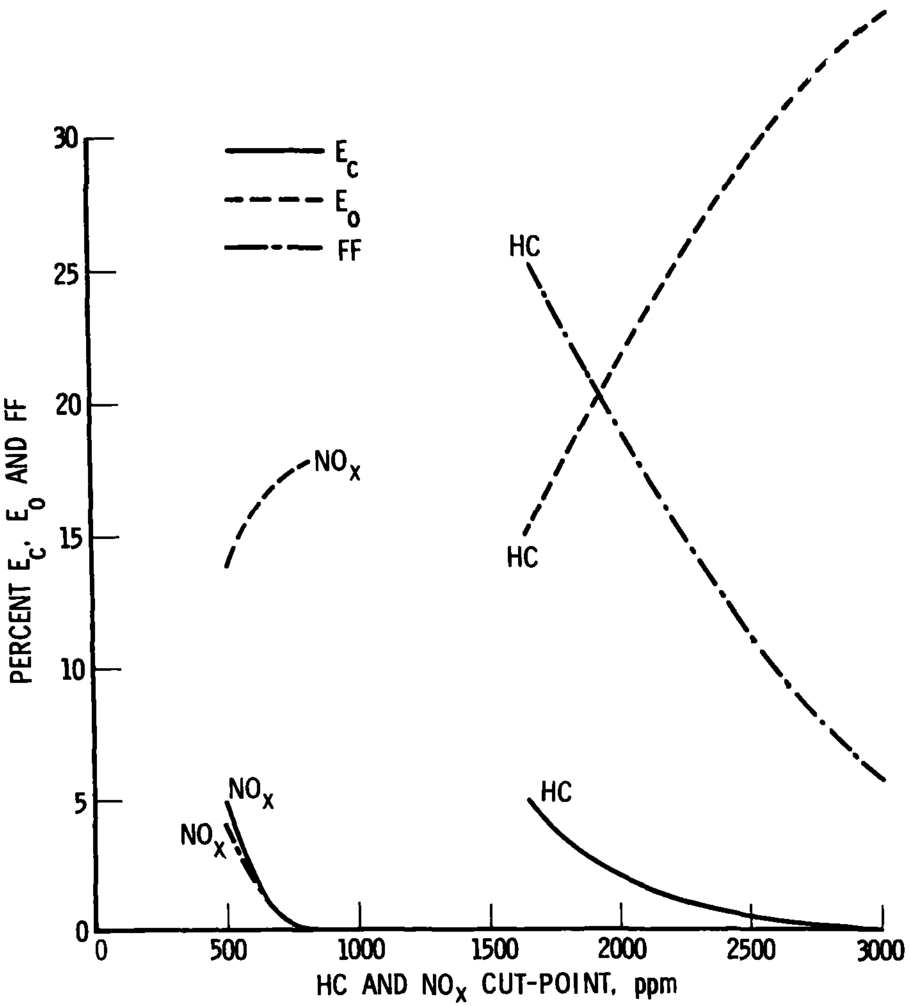


Figure 5-7. Variation of E_c, E_o, and FF with HC and NO_x Cut-Point; 1974 Model Year Fleet; Unloaded 2500 rpm Test; Bounded Errors of Commission Method

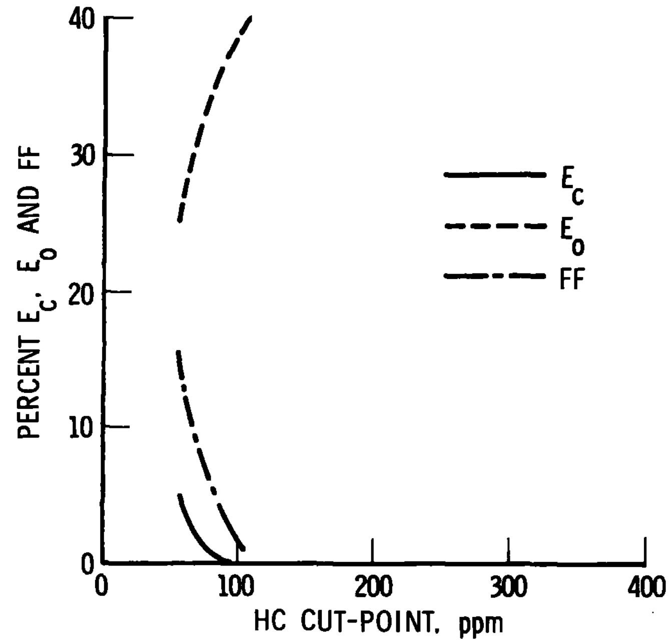


Figure 5-8. Variation of E_c, E_o, and FF with HC Cut-Point; 1974 Model Year Fleet; Unloaded 2500 rpm Test; Garage Instruments; Bounded Errors of Commission Method

Table 5-5. Comparison of ST Hydrocarbon Results: 1974 Model Year Fleet, Bounded Errors of Commission Analysis (E_c = constant = 5%)

Short Test	Parameter, %		Figure No.
	E_o	FF	
Federal Short Cycle	6.5	34.5	5-1
NY/NJ Composite	8.5	32	5-2
Clayton Key Mode (Laboratory)			
Idle	16	24.5	5-3
Low Speed	17	23.6	5-3
High Speed	18	22.5	5-3
Clayton Key Mode (Garage)			
Idle	11.5	29	5-4
Low Speed	14	27	5-4
High Speed	13	28	5-4
Federal Three-Mode (Laboratory)			
Idle	15.5	25	5-5
Low Speed	17.5	23	5-5
High Speed	18	23	5-5
Federal Three-Mode (Garage)			
Idle	17	24	5-6
Low Speed	14	27	5-6
High Speed	12	29	5-6
2500-rpm Unloaded (Laboratory)	16	26	5-7
2500-rpm Unloaded (Garage)	16	26	5-8

The bag tests (Federal Short Cycle and NY/NJ Composite) have lower E_o and higher FF at the fixed E_c = 5 percent condition than do the volumetric tests. There is little difference shown between the various volumetric STs.

5.2.2.1.2 Carbon Monoxide Emission

The variations of E_o, E_c, and FF as a function of CO cut-point are shown in Figures 5-9 through 5-16 for each ST examined. As in the preceding area of hydrocarbon emission, these figures indicate the possible tradeoffs between E_c, E_o, and FF. To illustrate specific values and trends among the STs, Table 5-6 summarizes data from the figures for the E_c value of 5 percent.

The bag-type STs (Federal Short Cycle and NY/NJ Composite) exhibit excellent CO tracking characteristics; the E_o values are considerably better (lower) than the volumetric tests, and the FF values are the highest. When garage-type instruments are used, the E_o values are essentially doubled (over laboratory instrument values) and FF values are significantly reduced.

5.2.2.1.3 Oxides of Nitrogen Emission

The variations of E_o, E_c and FF as a function of NO_x cut-point are shown in Figures 5-1, 5-2, 5-7, 5-17, and 5-18 for each ST examined. The significant results at the E_c level of 5 percent are summarized in Table 5-7 for comparative purposes. As can be noted, all STs identified very low percentages of correctly failed vehicles (FF), <5 percent, while having significant errors of omission, ~15 percent.

5.2.2.1.4 Variance Estimates

The general variance trends discussed in Sec. 4.2.2.5.1.5 for the CEV fleet are also applicable in this case. However, the actual magnitude of the standard deviation is different for the 1974 model year fleet. For the example illustrated in Sec. 4.2.2.5.1.5, the Federal Short Cycle HC cut-point is 2.6 gm/mi at γ = 0.045 (Figure 5-1). PF is 0.048 and

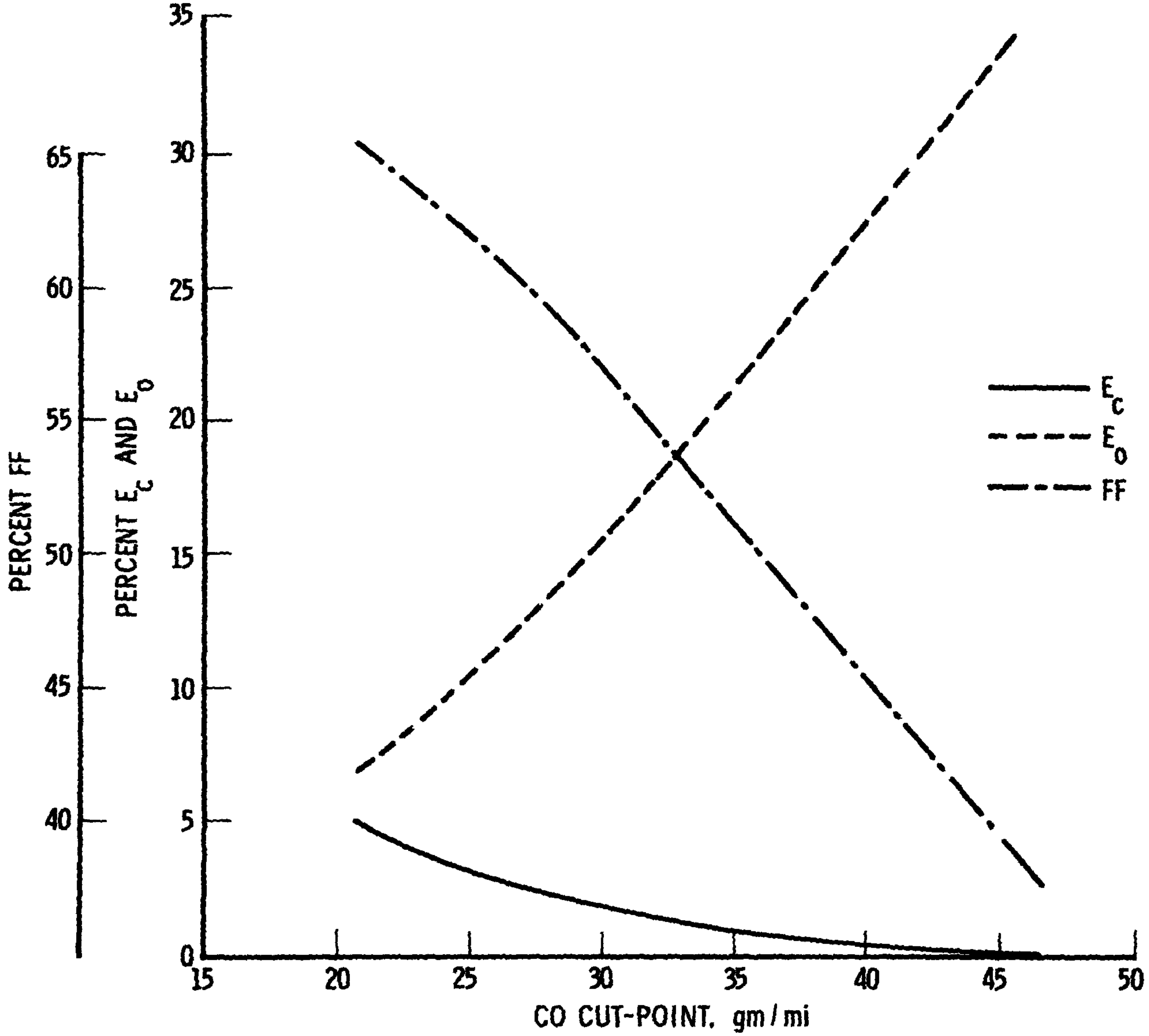


Figure 5-9. Variation of E_C, E_O, and FF with CO Cut-Point; 1974 Model Year Fleet; Federal Short Cycle Test; Bounded Errors of Commission Method

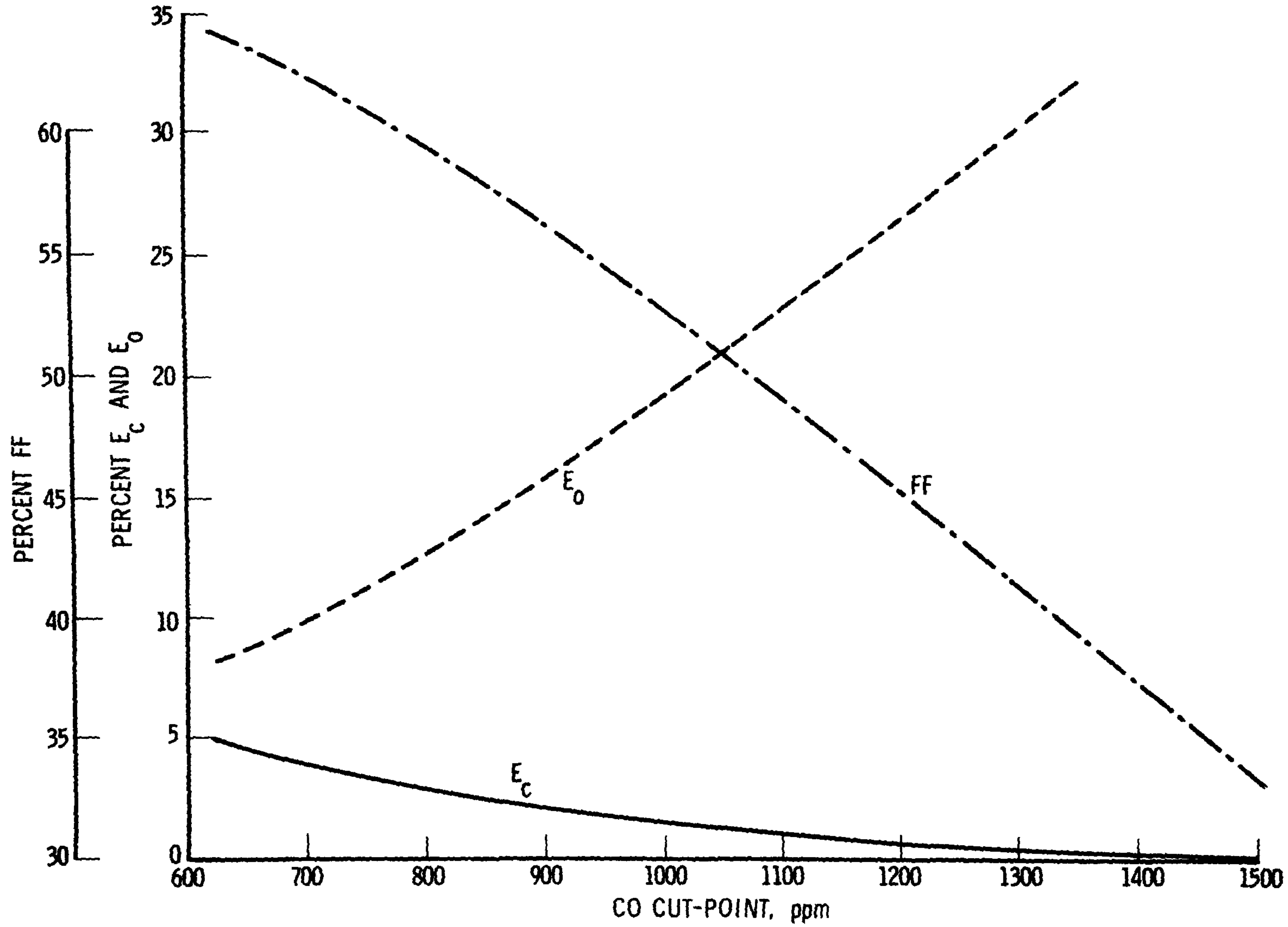


Figure 5-10. Variation of E_C, E_O, and FF with CO Cut-Point; 1974 Model Year Fleet; NY/NJ Composite Test; Bounded Errors of Commission Method

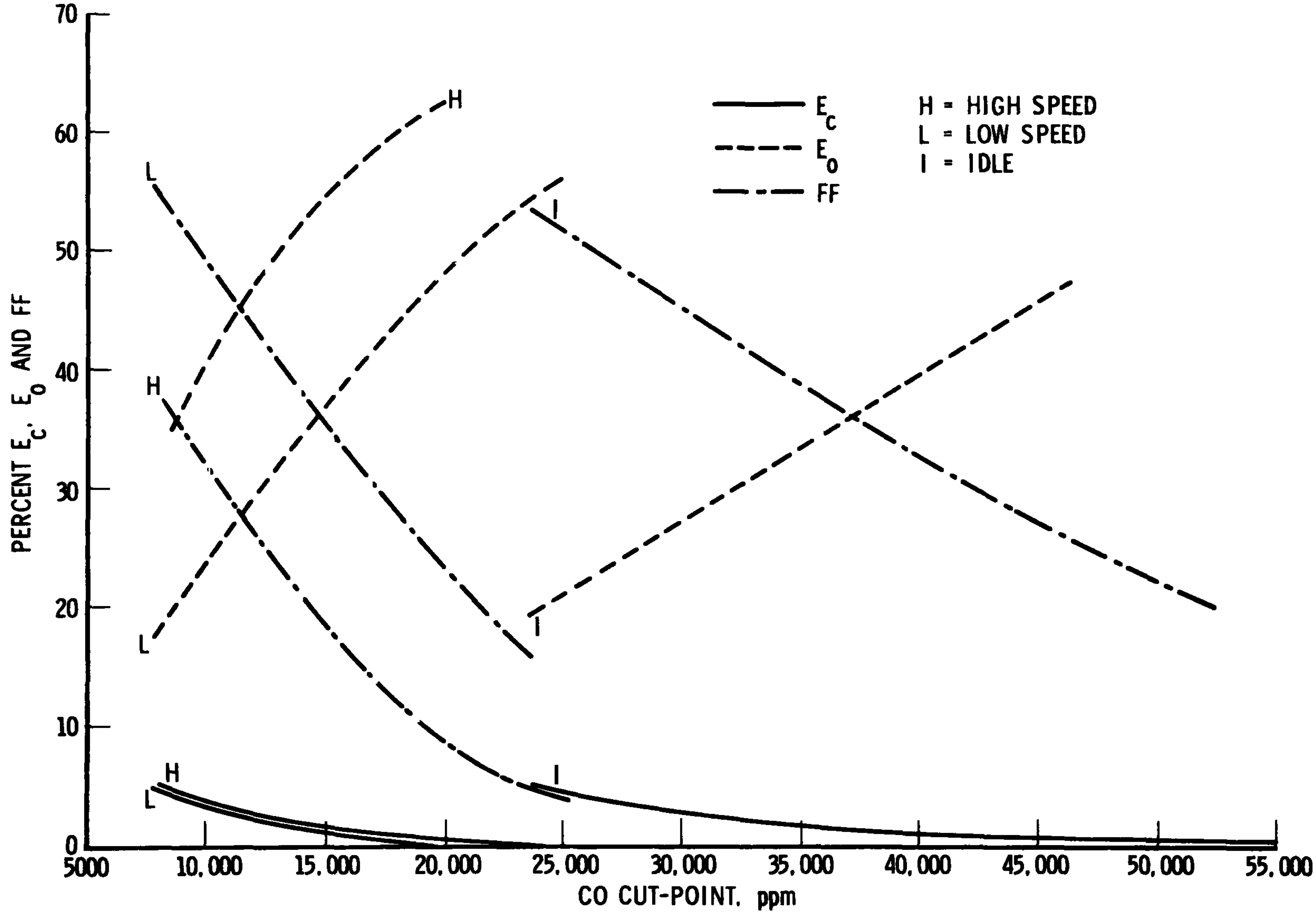


Figure 5-11. Variation of E_C, E_O, and FF with CO Cut-Point; 1974 Model Year Fleet; Key Mode Test; Bounded Errors of Commission Method

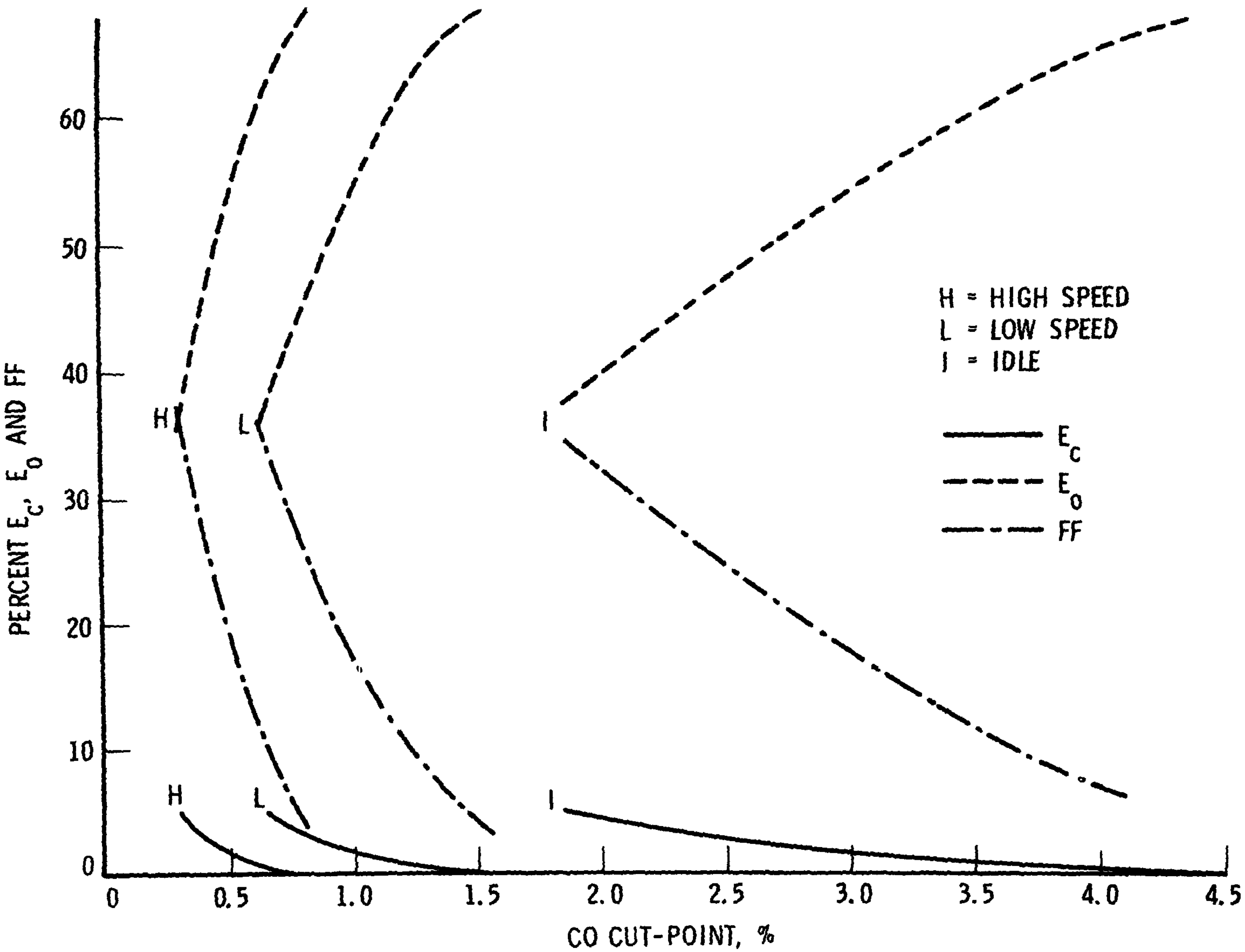


Figure 5-12. Variation of E_C, E_O, and FF with CO Cut-Point; 1974 Model Year Fleet; Key Mode Test; Garage Instruments; Bounded Errors of Commission Method

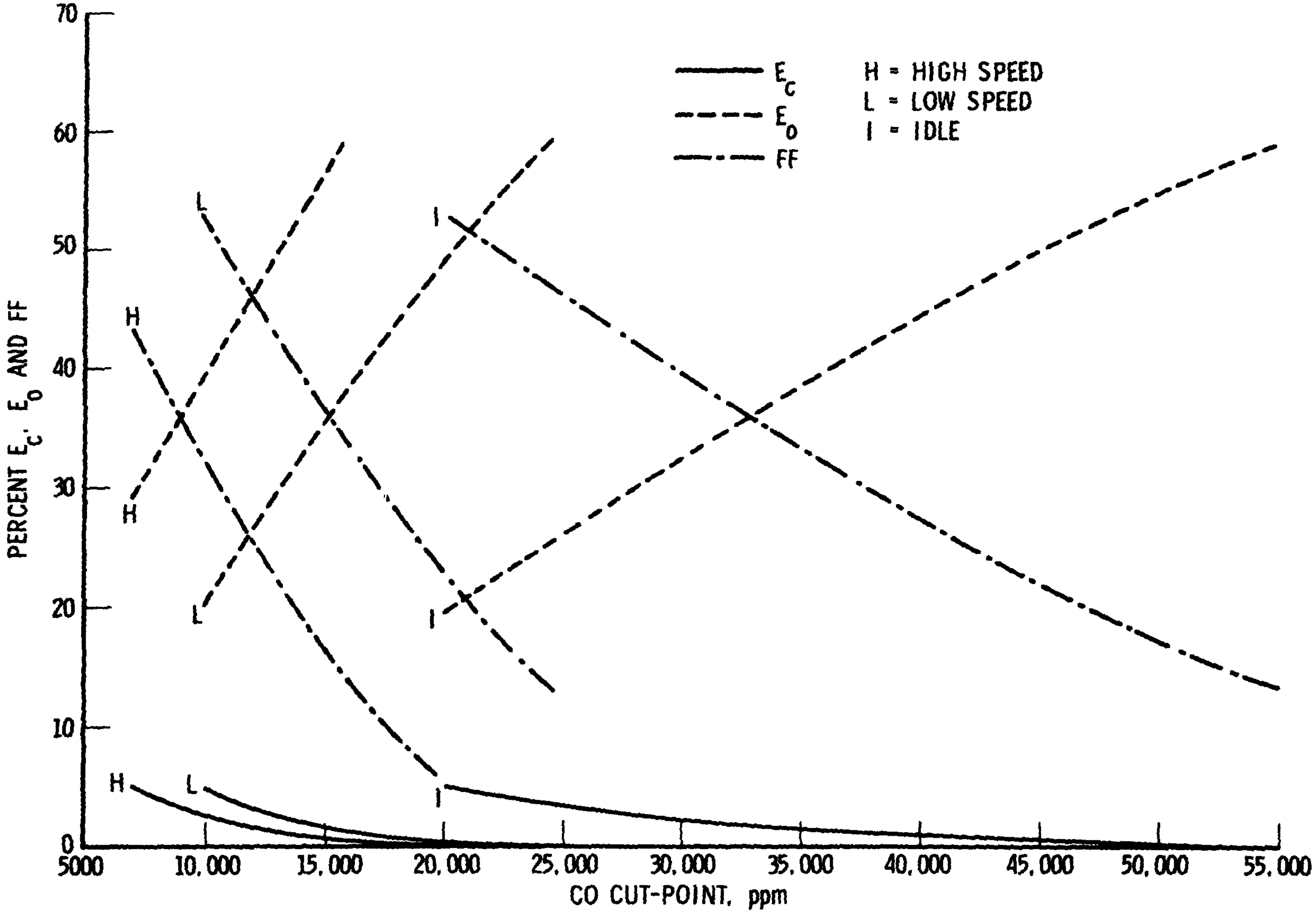


Figure 5-13. Variation of E_c, E_o, and FF with CO Cut-Point; 1974 Model Year Fleet; Federal Three-Mode Test; Bounded Errors of Commission Method

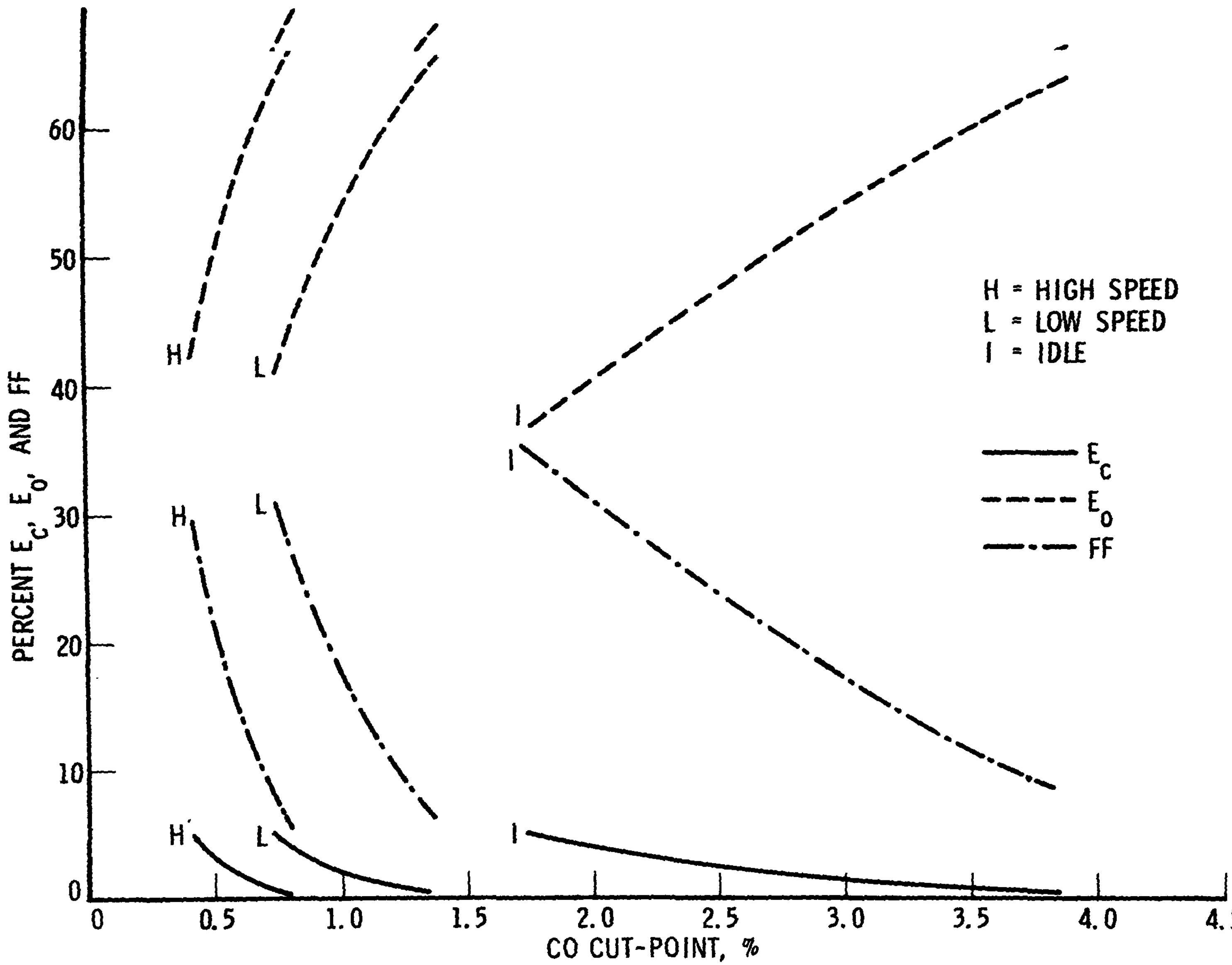


Figure 5-14. Variation of E_c, E_o, and FF with CO Cut-Point; 1974 Model Year Fleet; Federal Three-Mode Test; Garage Instruments; Bounded Errors of Commission Method

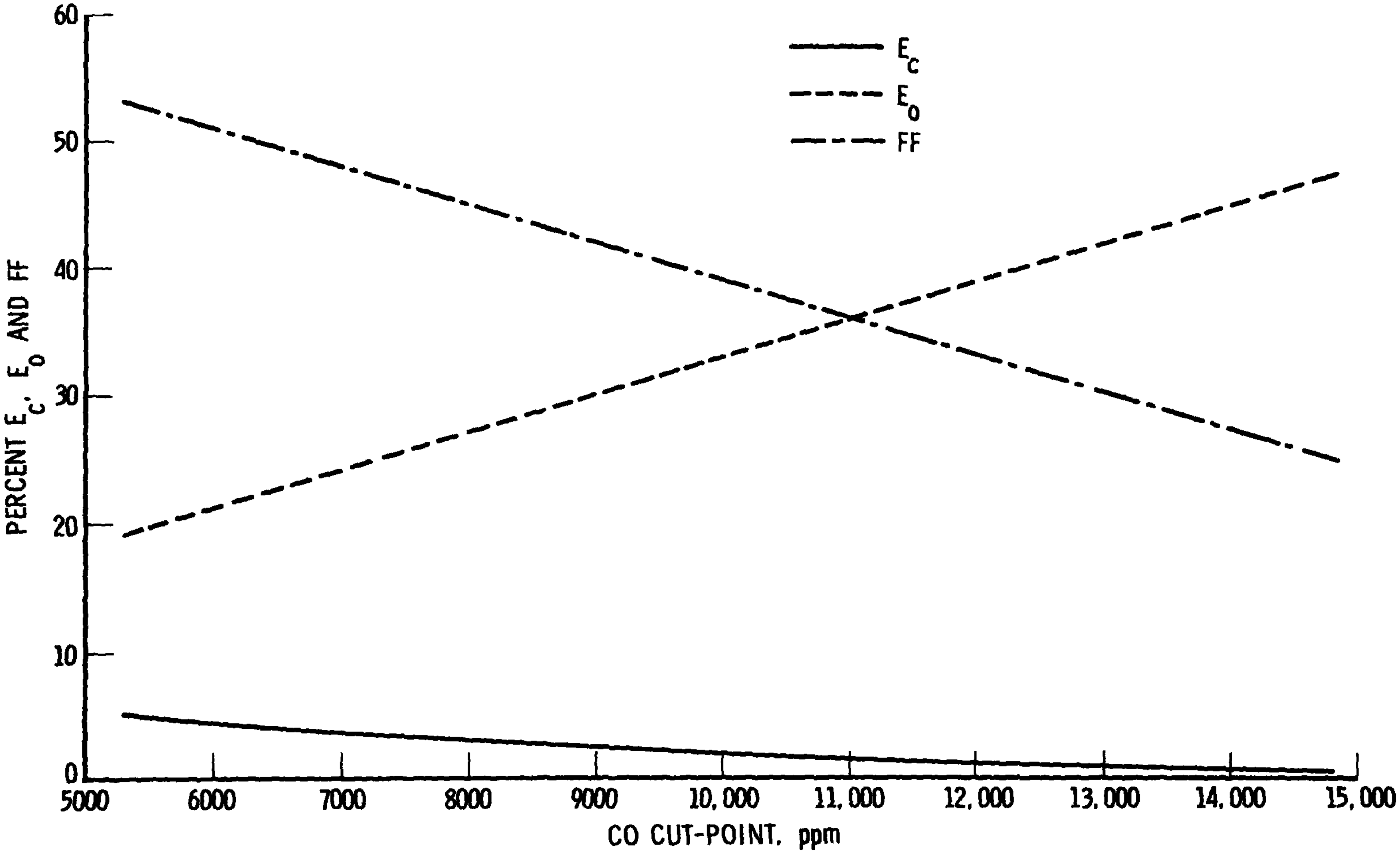


Figure 5-15. Variation of E_c, E_o, and FF with CO Cut-Point; 1974 Model Year Fleet; Unloaded 2500 rpm Test; Bounded Errors of Commission Method

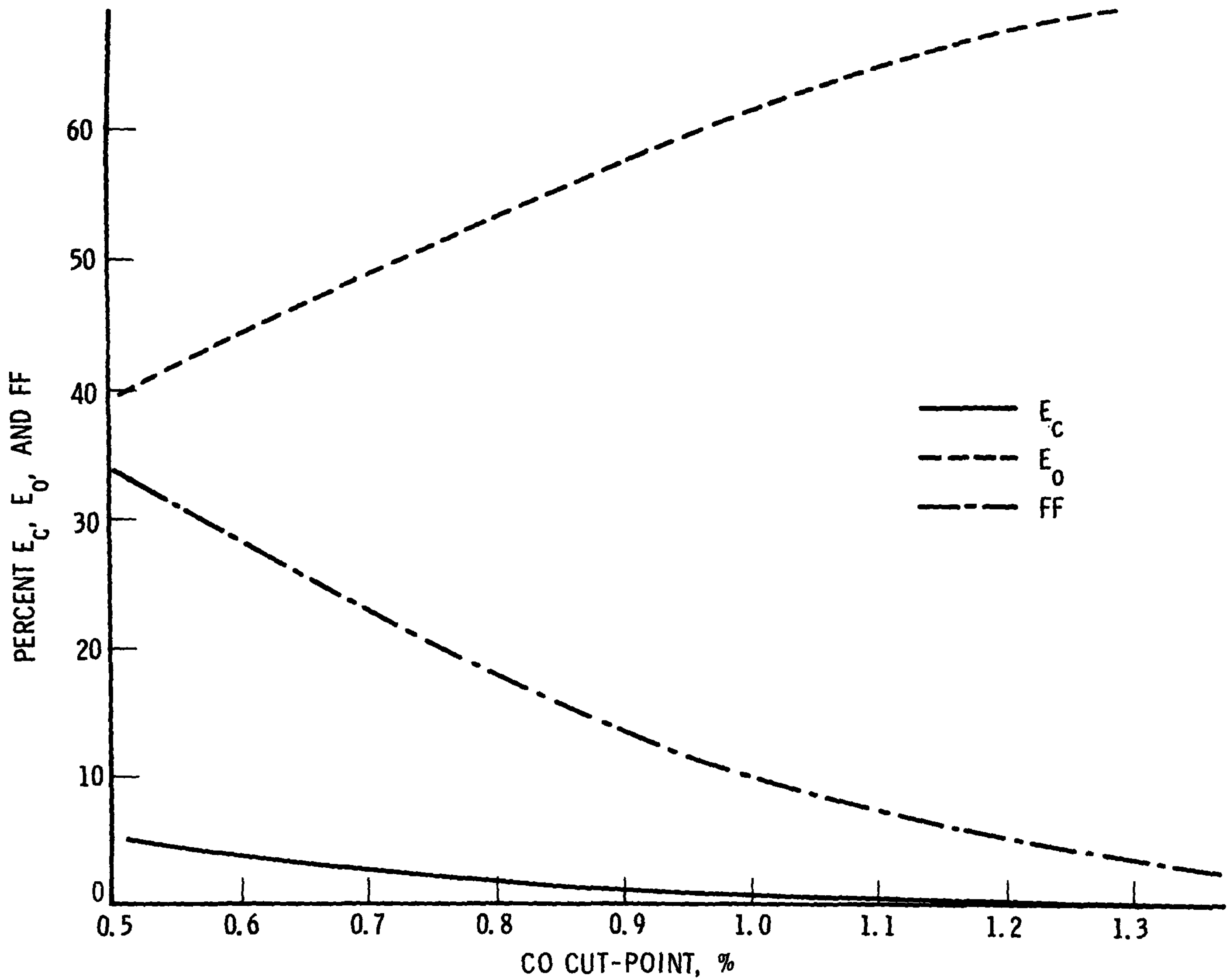


Figure 5-16. Variation of E_c, E_o, and FF with CO Cut-Point; 1974 Model Year Fleet; Unloaded 2500 rpm Test; Garage Instruments; Bounded Errors of Commission Method

Table 5-6. Comparison of ST Carbon Monoxide Results: 1974 Model Year Fleet, Bounded Errors of Commission Analysis (E_c = constant = 5%)

Short Test	Parameter, %		Figure No.
	E_o	FF	
Federal Short Cycle	7	65	5-9
NY/NJ Composite	8	64	5-10
Clayton Key Mode (Laboratory)			
Idle	19	53	5-11
Low Speed	18	54	5-11
High Speed	35	38	5-11
Clayton Key Mode (Garage)			
Idle	35	38	5-12
Low Speed	35	38	5-12
High Speed	37	35	5-12
Federal Three-Mode (Laboratory)			
Idle	20	53	5-13
Low Speed	20	52	5-13
High Speed	29	43	5-13
Federal Three-Mode (Garage)			
Idle	35	37	5-14
Low Speed	31	41	5-14
High Speed	30	42	5-14
2500-rpm Unloaded (Laboratory)	19	53	5-15
2500-rpm Unloaded (Garage)	33	40	5-16

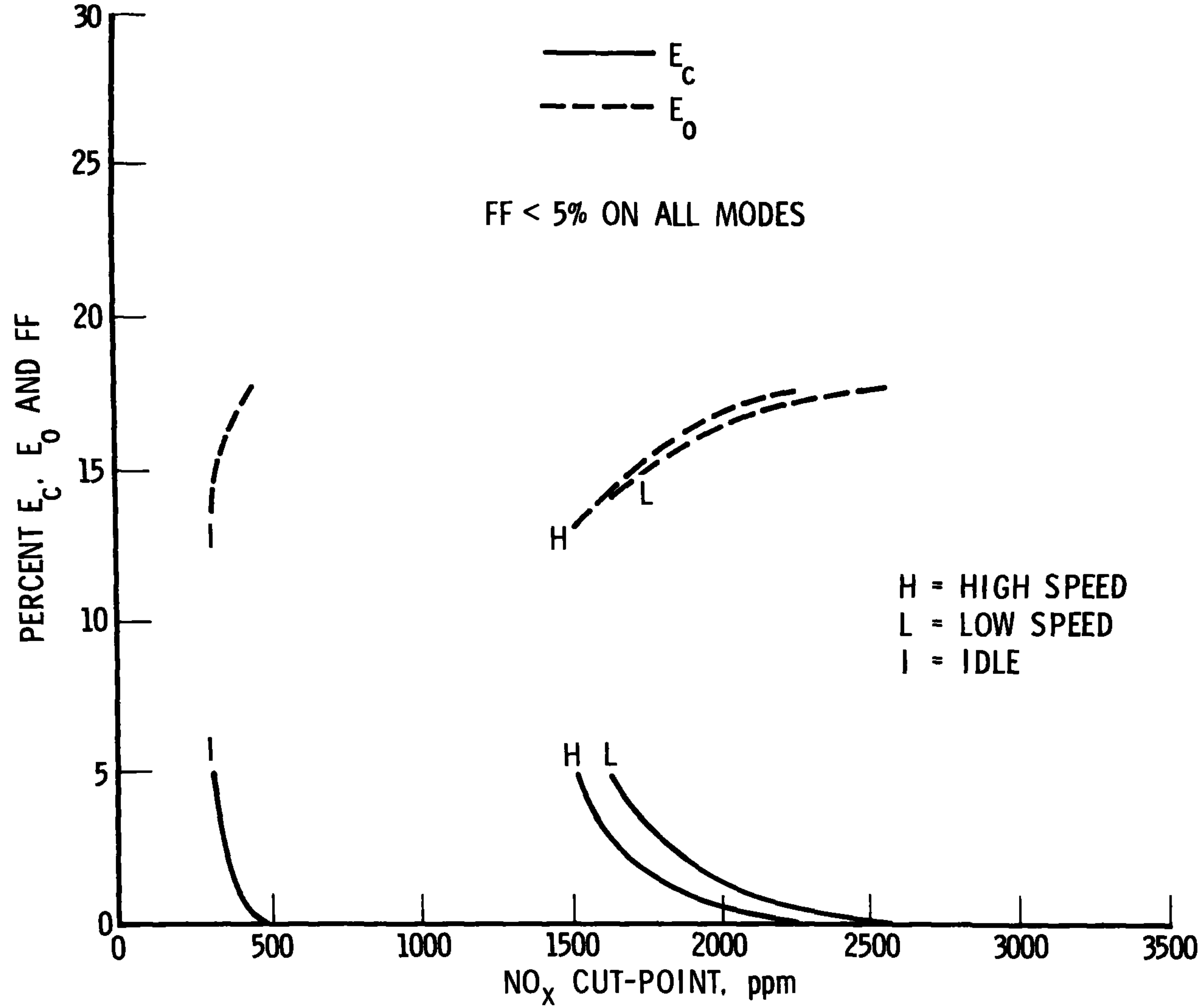


Figure 5-17. Variation of E_c, E_o, and FF with NO_x Cut-Point; 1974 Model Year Fleet; Key Mode Test; Bounded Errors of Commission Method

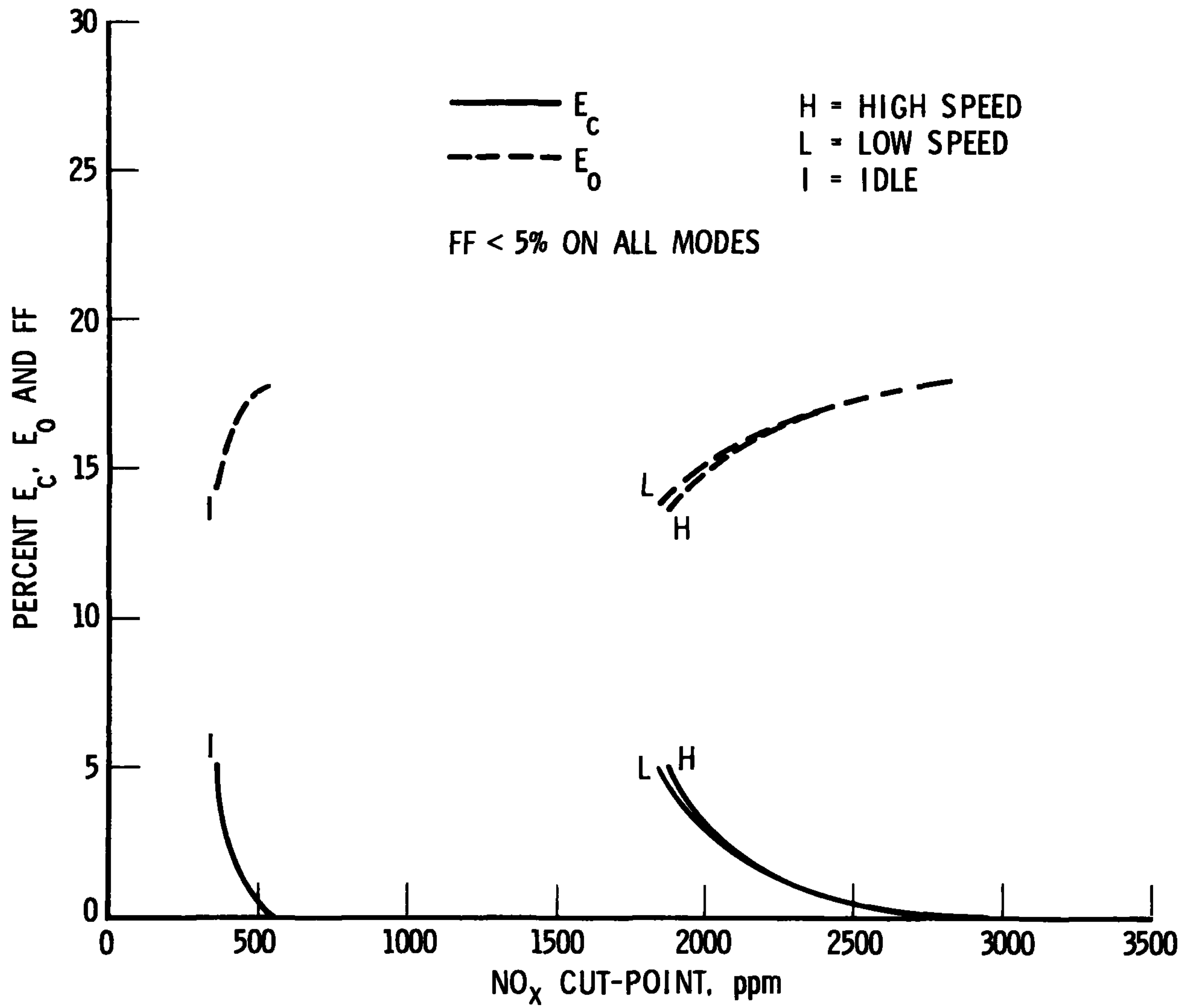


Figure 5-18. Variation of E_c, E_o, and FF with NO_x Cut-Point; 1974 Model Year Fleet; Federal Three-Mode Test; Bounded Errors of Commission Method

Table 5-7. Comparison of ST NO_x Results: 1974 Model Year Fleet, Bounded Errors of Commission Analysis (E_c = constant = 5%)

Short Test	Parameter, %		Figure No.
	E_o	FF	
Federal Short Cycle	14.5	3	5-1
NY/NJ Composite	16.5	1.5	5-2
Clayton Key Mode (Laboratory)			
Idle	13.5	<5	5-17
Low Speed	14	<5	5-17
High Speed	13.5	<5	5-17
Federal Three-Mode (Laboratory)			
Idle	14	<5	5-18
Low Speed	14	<5	5-18
High Speed	14	<5	5-18
2500-rpm Unloaded (Laboratory)	14	4	5-7

$$\left|\frac{dp(y)}{dy}\right|_{y=2.6} \simeq 0.02$$

With N = 147, Eq. (4-1) yields a standard deviation of 0.35 gm/mi. At $\gamma = 0.005$, the standard deviation is about 0.95 gm/mi where the cut-point is 3.2 gm/mi. The standard deviation on CO (Figure 5-9) is estimated at 2.4 gm/mi for the cut-point at 21.5 gm/mi. For CO at $\gamma = 0.005$, the cut-point is 38 gm/mi and the standard deviation is approximately 4.9 gm/mi.

These estimates show that the standard deviation is on the order of 10 percent to 15 percent of the estimated cut-point.

5.2.2.1.5 Instrument Comparisons

For comparing the instruments used in the test program, plots of the type shown in Figures 5-19 through 5-32 are informative. Here percent E_o and percent FF have been plotted against percent E_c for HC and CO with each modal ST. If a policy decision is given in terms of percent E_c allowable, then the percent FF and percent E_o can be compared. To illustrate, , , suppose percent E_c is fixed at 3 percent. For CO on the low speed Key Mode (Figure 5-22), the laboratory instruments (dashed lines) give 48 percent FF and 24 percent E_o, while the garage instruments give 26 percent FF and 46 percent E_o.

If policy is stipulated in terms of percent rejected by the ST, then percent E_c can be compared. For the CO low-speed mode on the Key Mode test, suppose ST percentage rejection is to be approximately 30 percent. Then, for percent FF equal to 30 percent (percent E_o equals 42 percent), percent E_c is 0.6 percent for the laboratory instruments and 3.9 percent for the garage instruments.

5.2.2.1.6 Discussion of Results

On the average, the bag-type tests have lower E_o and higher FF for a fixed rate of E_c than do the volumetric tests. However, FF rates in the 30 percent range can be achieved with any of the tests. For a fixed percent FF, the percent E_o is determined since the sum of FF and E_o is the

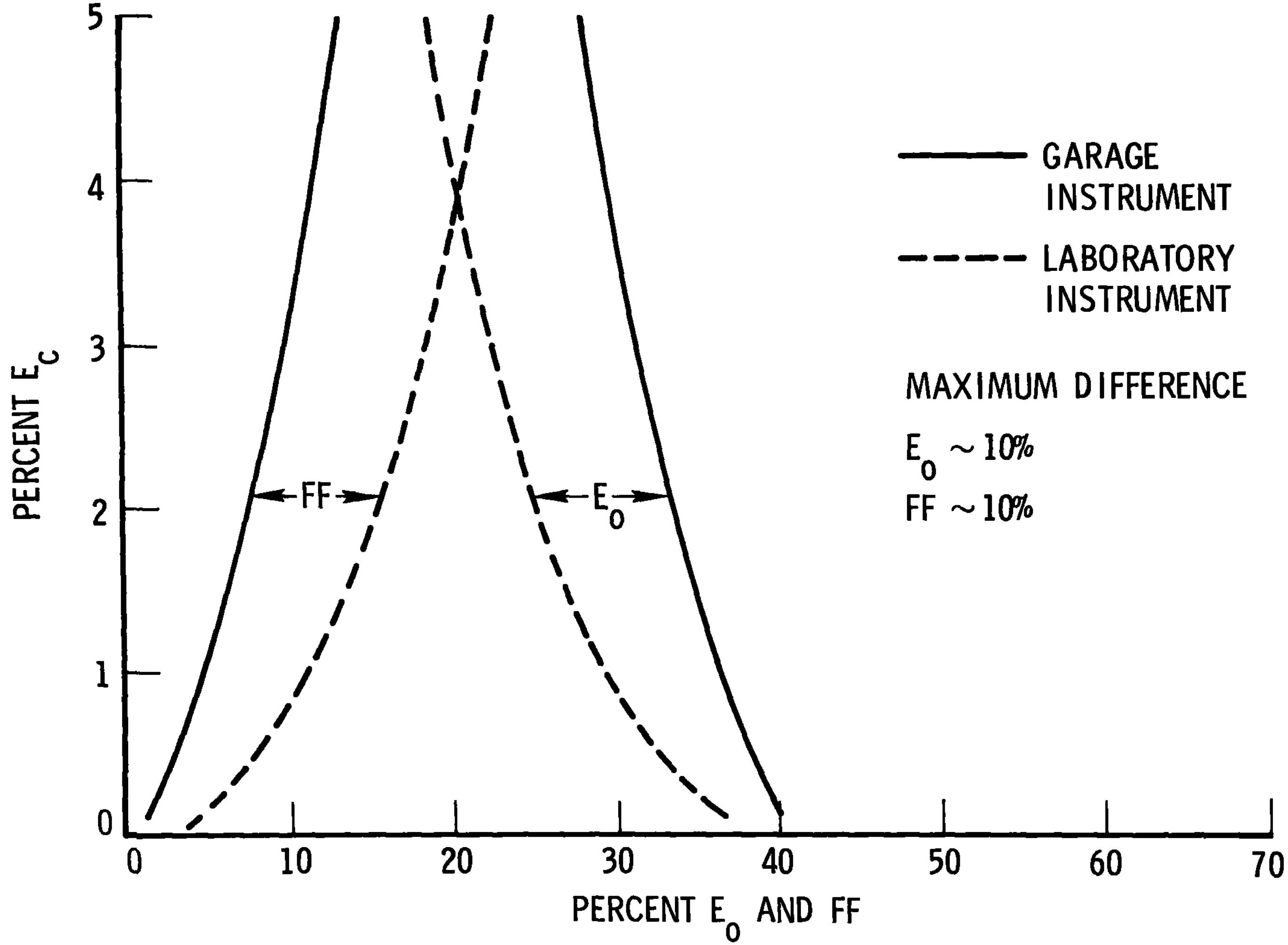


Figure 5-19. Variation of E_c, E_o, and FF with Instrument Type; HC; 1974 Model Year Fleet; Key Mode Test; High Speed Mode; Bounded Errors of Commission Method

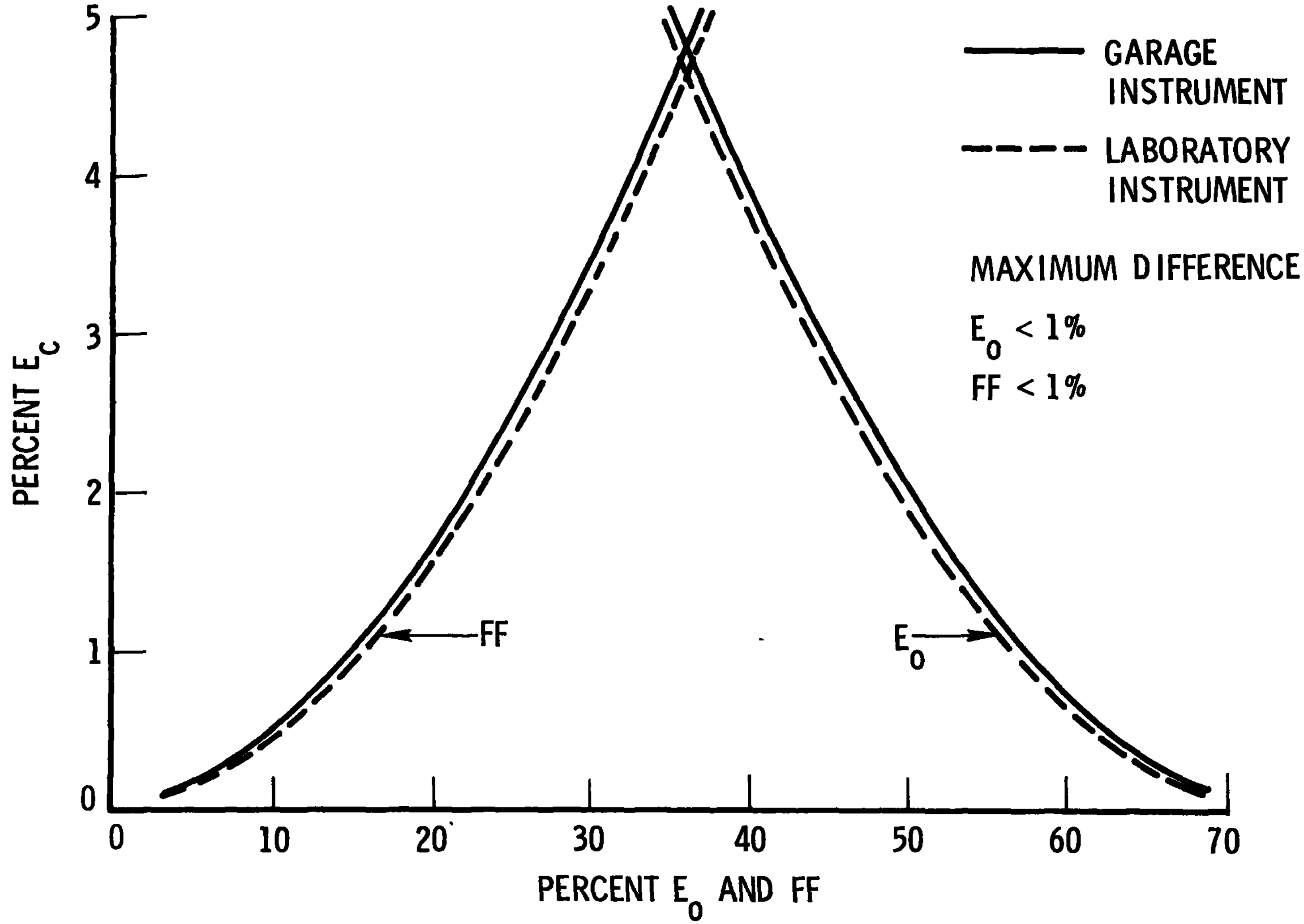


Figure 5-20. Variation of E_C, E_O, and FF with Instrument Type; CO; 1974 Model Year Fleet; Key Mode Test; High Speed Mode; Bounded Errors of Commission Method

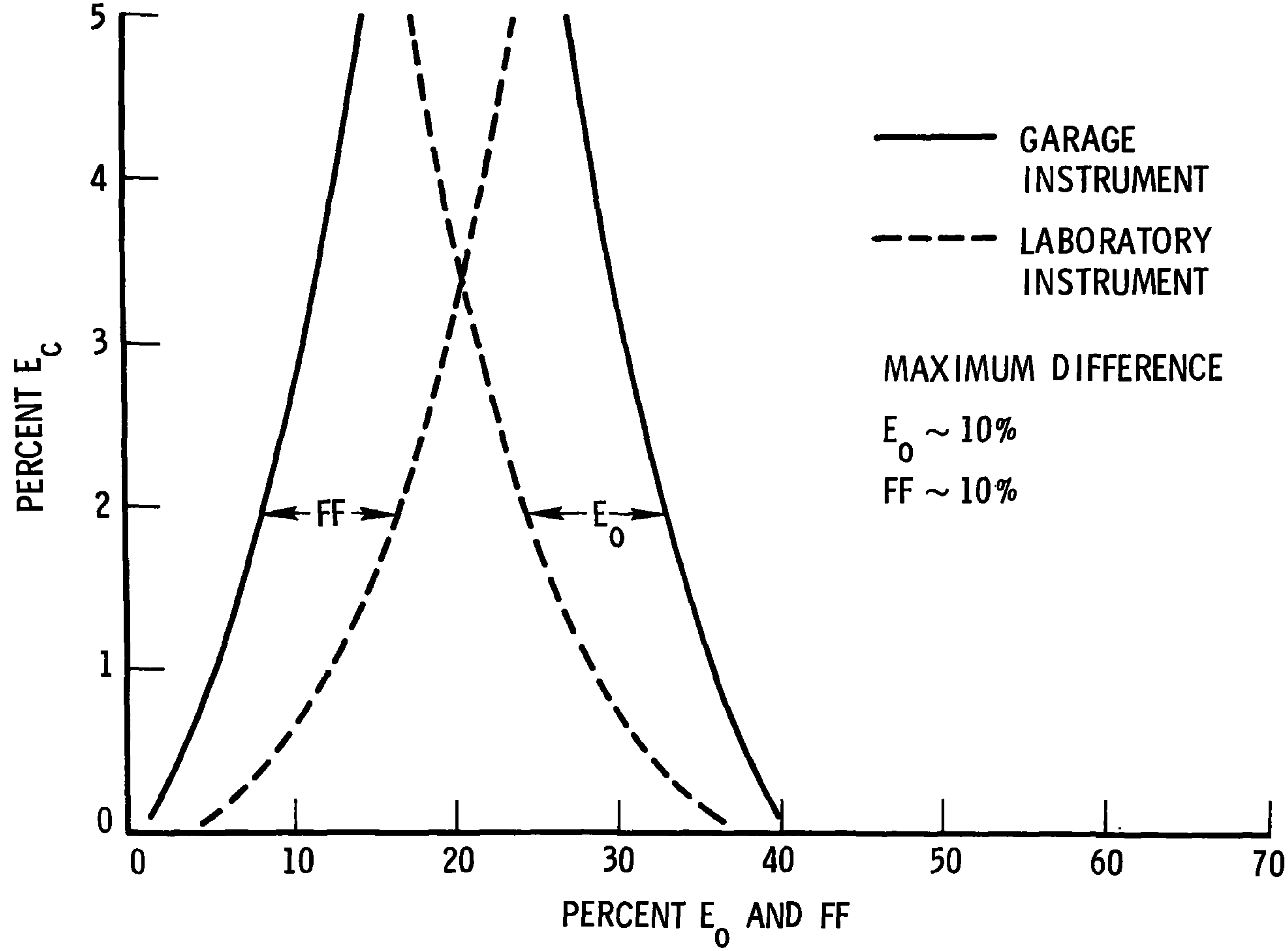


Figure 5-21. Variation of E_c, E_o, and FF with Instrument Type; HC; 1974 Model Year Fleet; Key Mode Test; Low Speed Mode; Bounded Errors of Commission Method

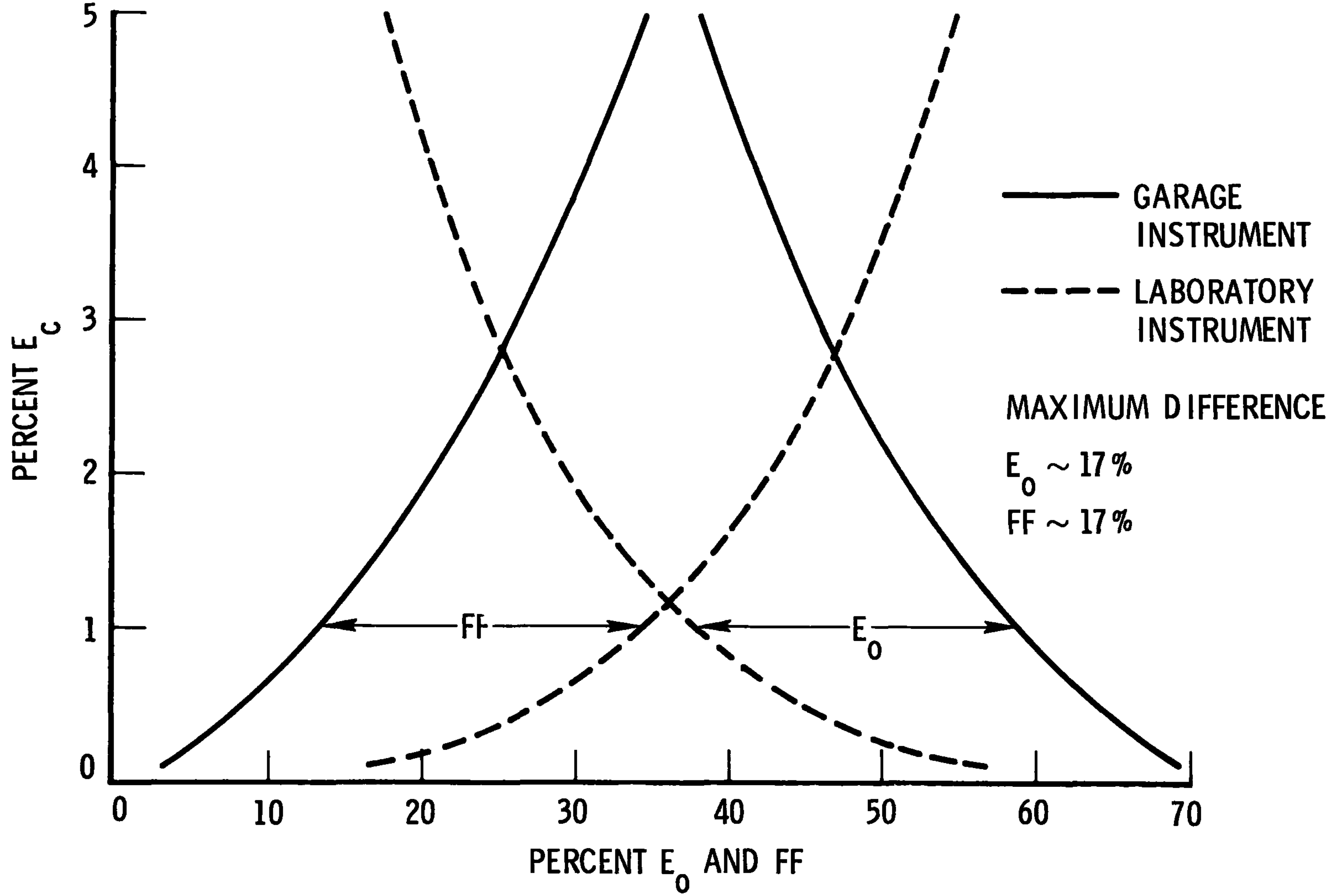


Figure 5-22. Variation of E_C, E_O, and FF with Instrument Type; CO; 1974 Model Year Fleet; Key Mode Test; Low Speed Mode; Bounded Errors of Commission Method

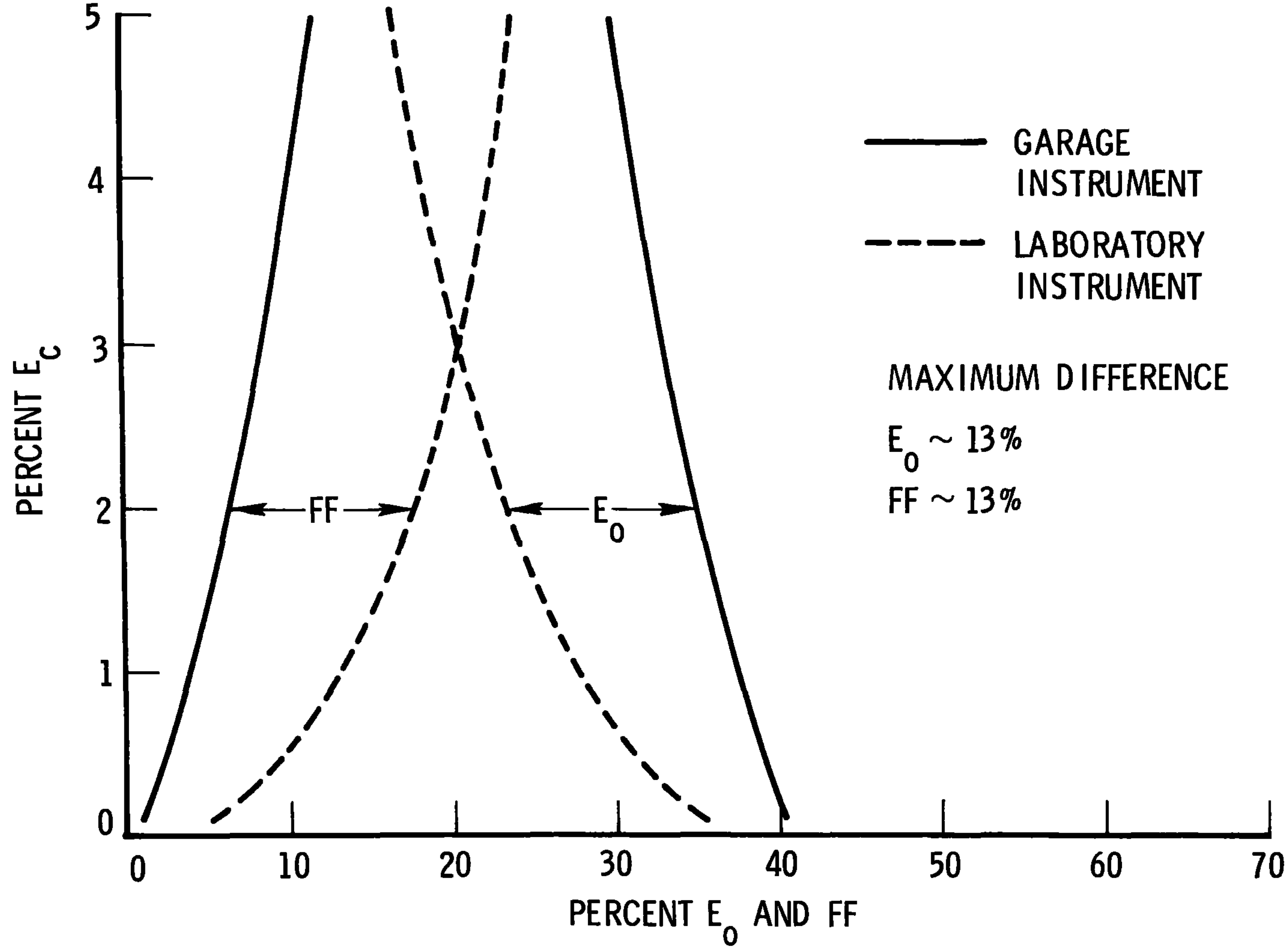


Figure 5-23. Variation of E_C, E_O, and FF with Instrument Type; HC; 1974 Model Year Fleet; Key Mode Test; Idle Mode; Bounded Errors of Commission Method

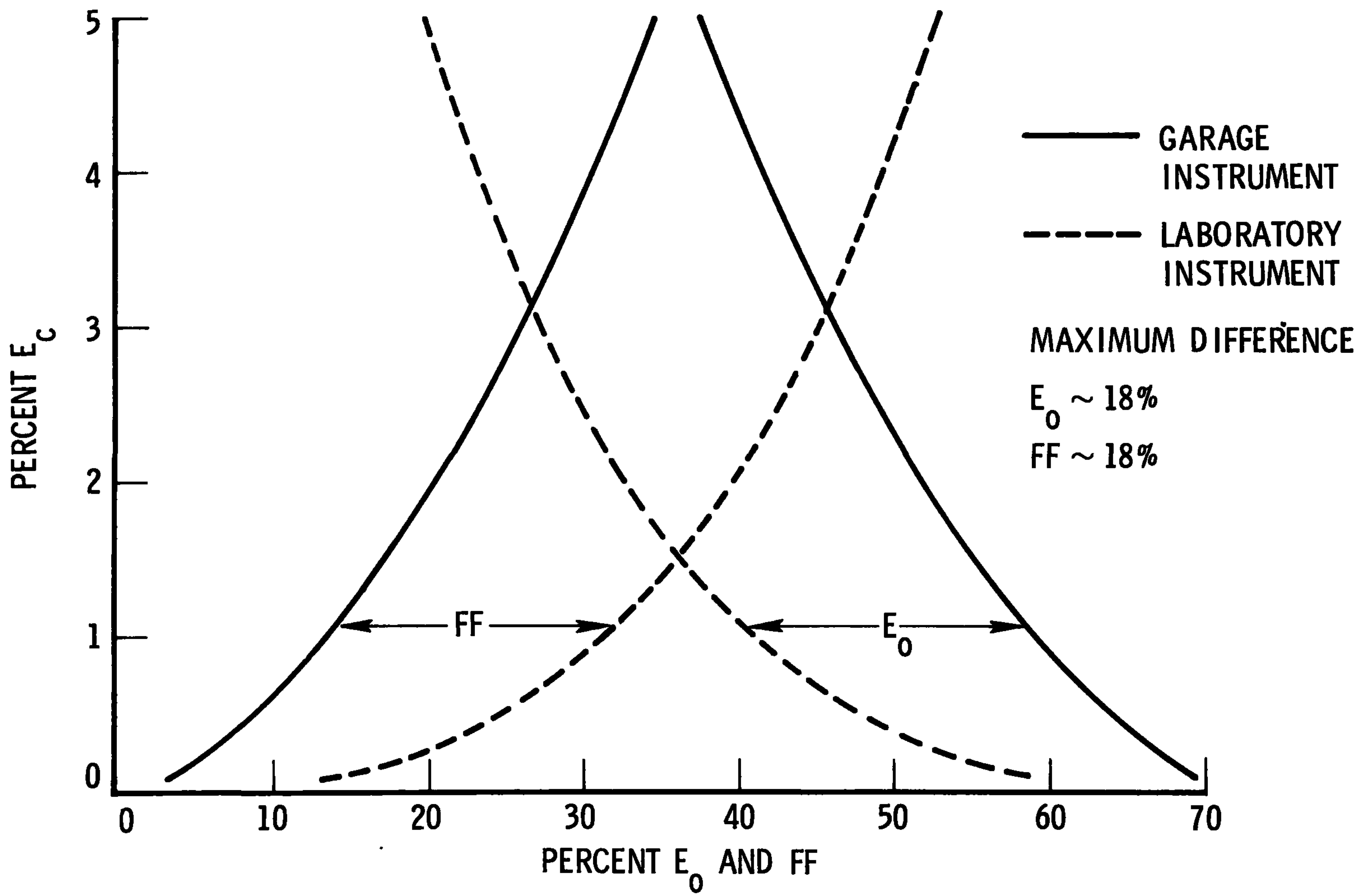


Figure 5-24. Variation of E_c, E_o, and FF with Instrument Type; CO; 1974 Model Year Fleet, Key Mode Test; Idle Mode; Bounded Errors of Commission Method

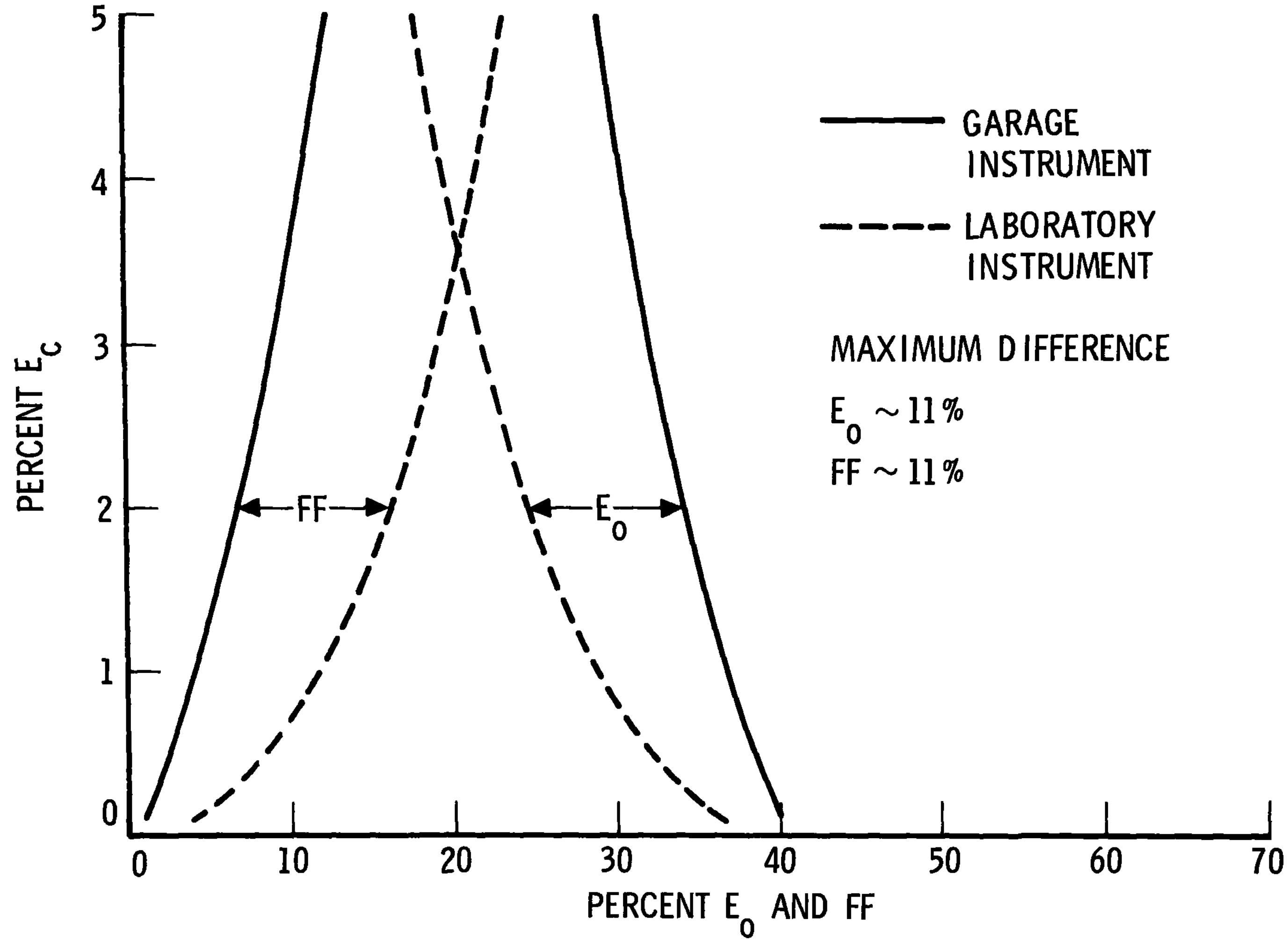


Figure 5-25. Variation of E_c, E_o, and FF with Instrument Type; HC; 1974 Model Year Fleet; Federal Three-Mode Test; High Speed Mode; Bounded Errors of Commission Method

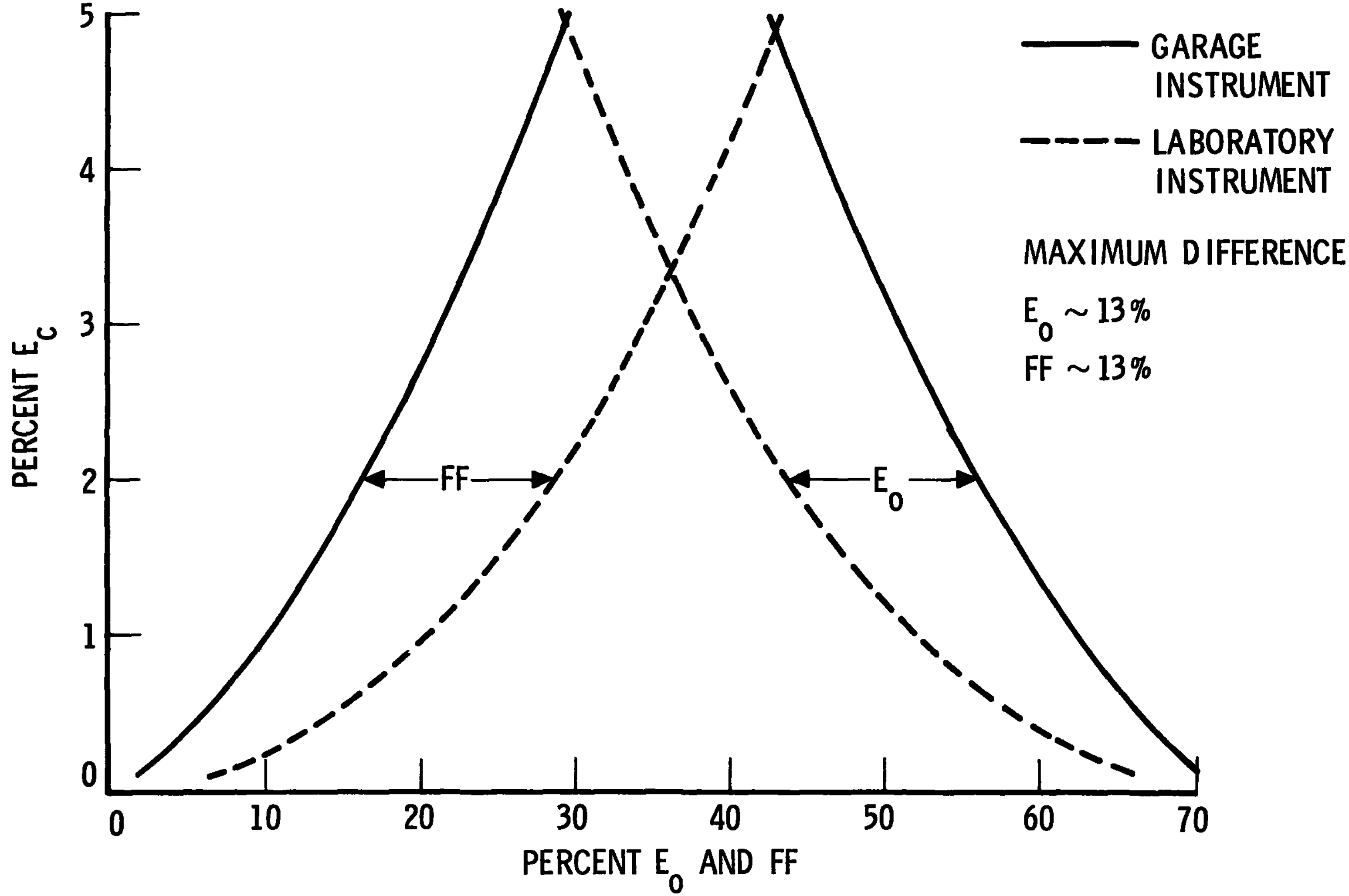


Figure 5-26. Variation of E_c, E_o, and FF with Instrument Type; CO; 1974 Model Year Fleet; Federal Three-Mode Test; High Speed Mode; Bounded Errors of Commission Method

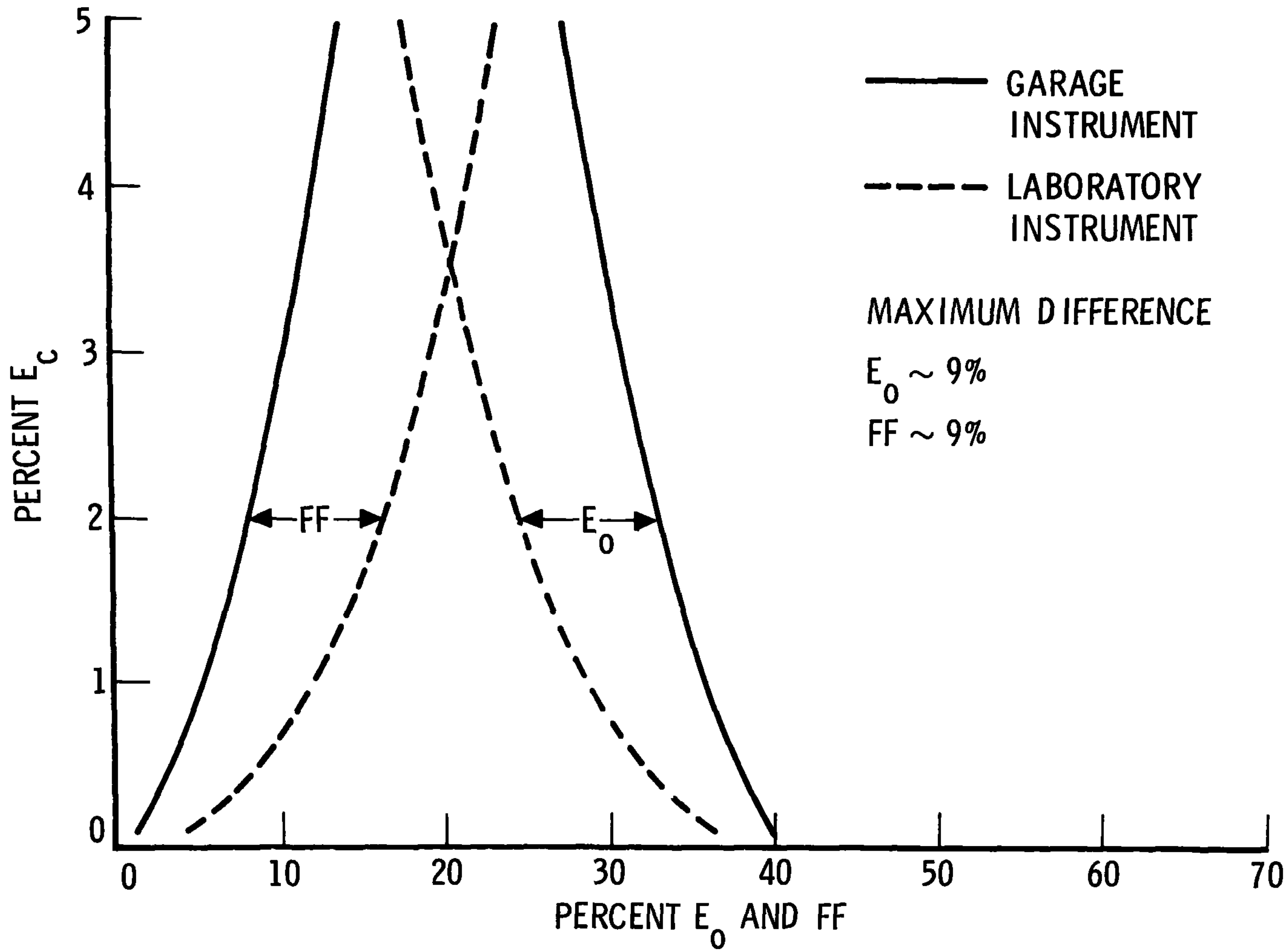


Figure 5-27. Variation of E_C, E_O, and FF with Instrument Type; HC; 1974 Model Year Fleet; Federal Three-Mode Test; Low Speed Mode; Bounded Errors of Commission Method

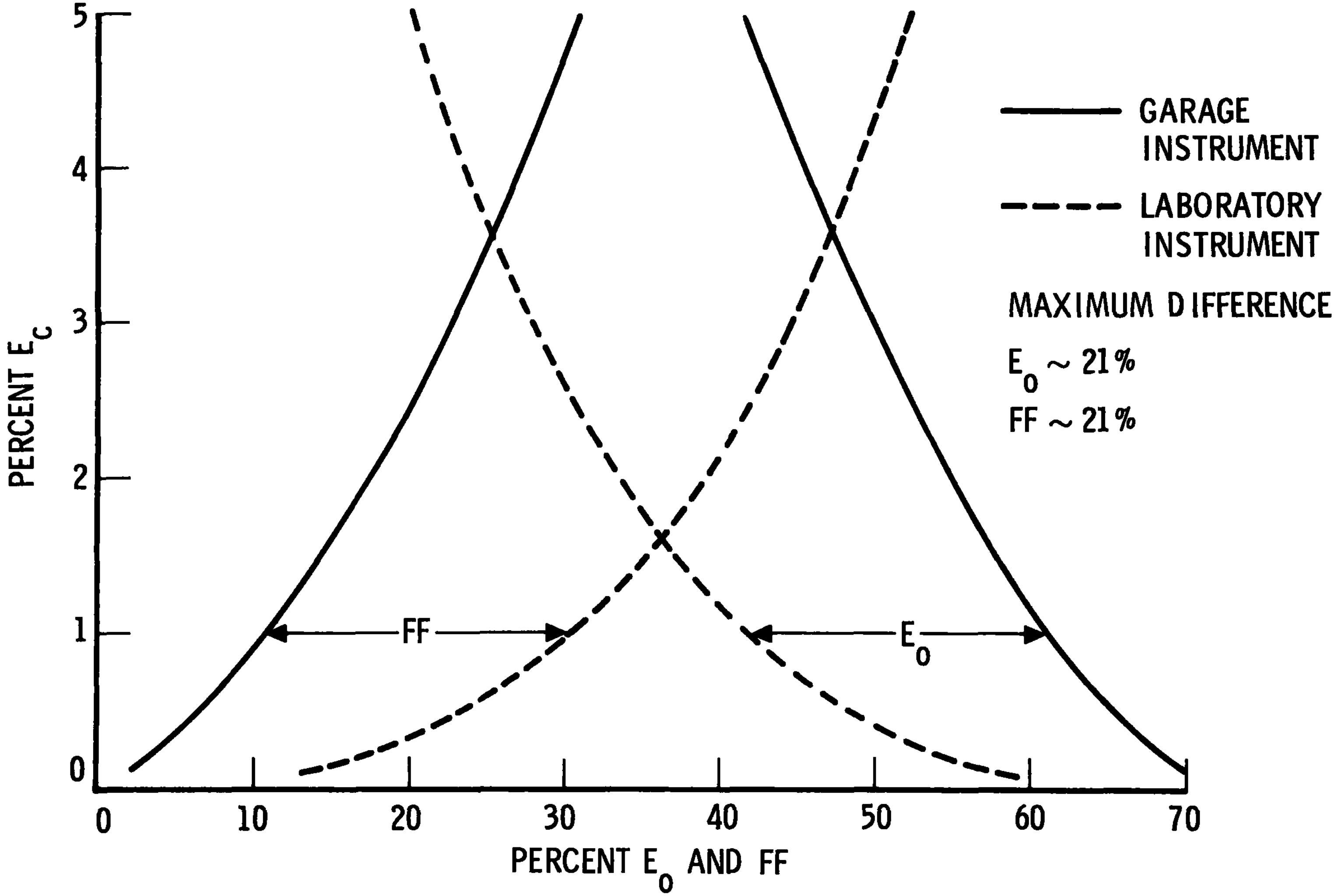


Figure 5-28. Variation of E_C, E_O, and FF with Instrument Type; CO; 1974 Model Year Fleet; Federal Three-Mode Test; Low Speed Mode; Bounded Errors of Commission Method

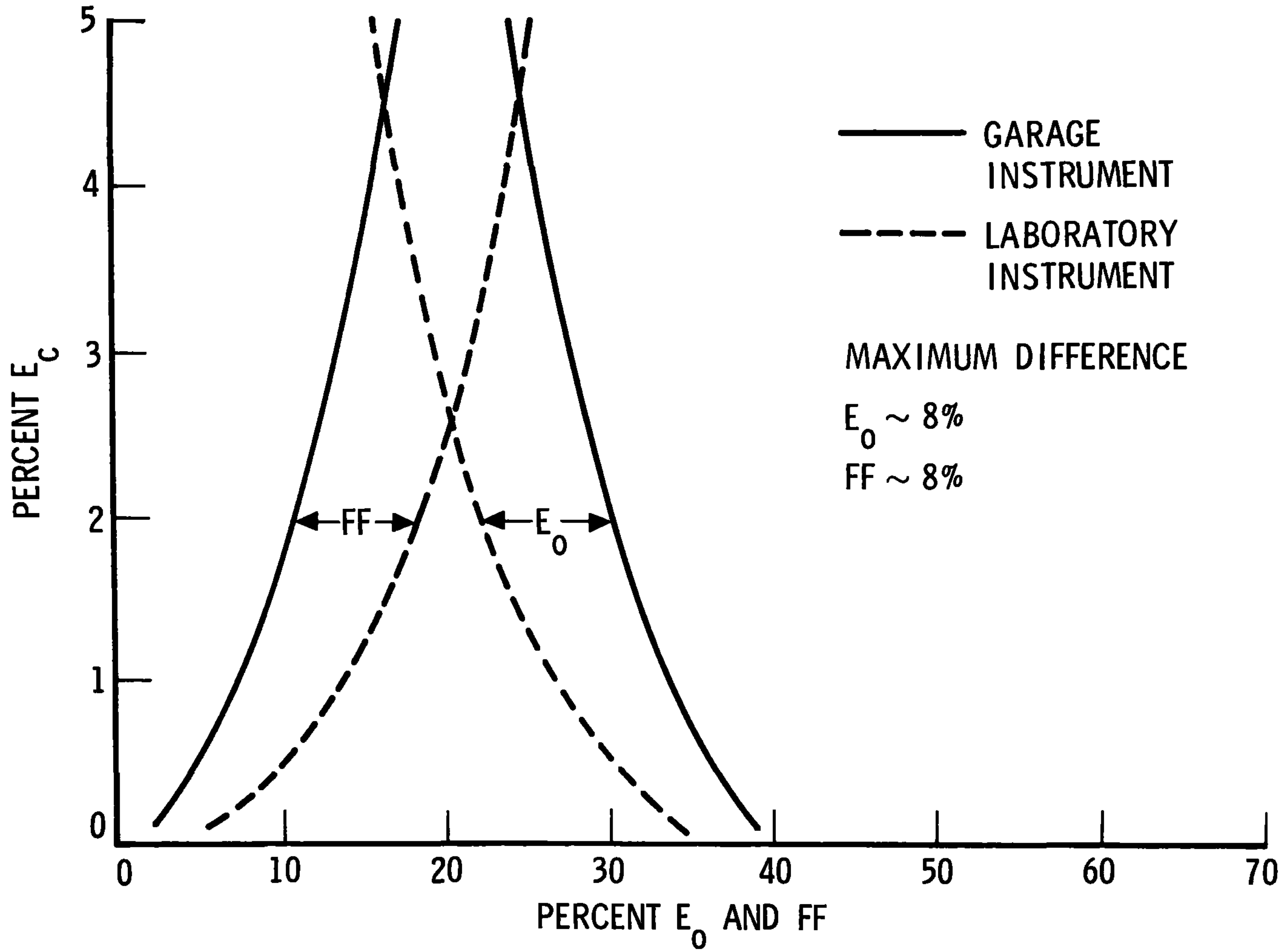


Figure 5-29. Variation of E_c, E_o, and FF with Instrument Type; HC; 1974 Model Year Fleet; Federal Three-Mode Test; Idle Mode; Bounded Errors of Commission Method

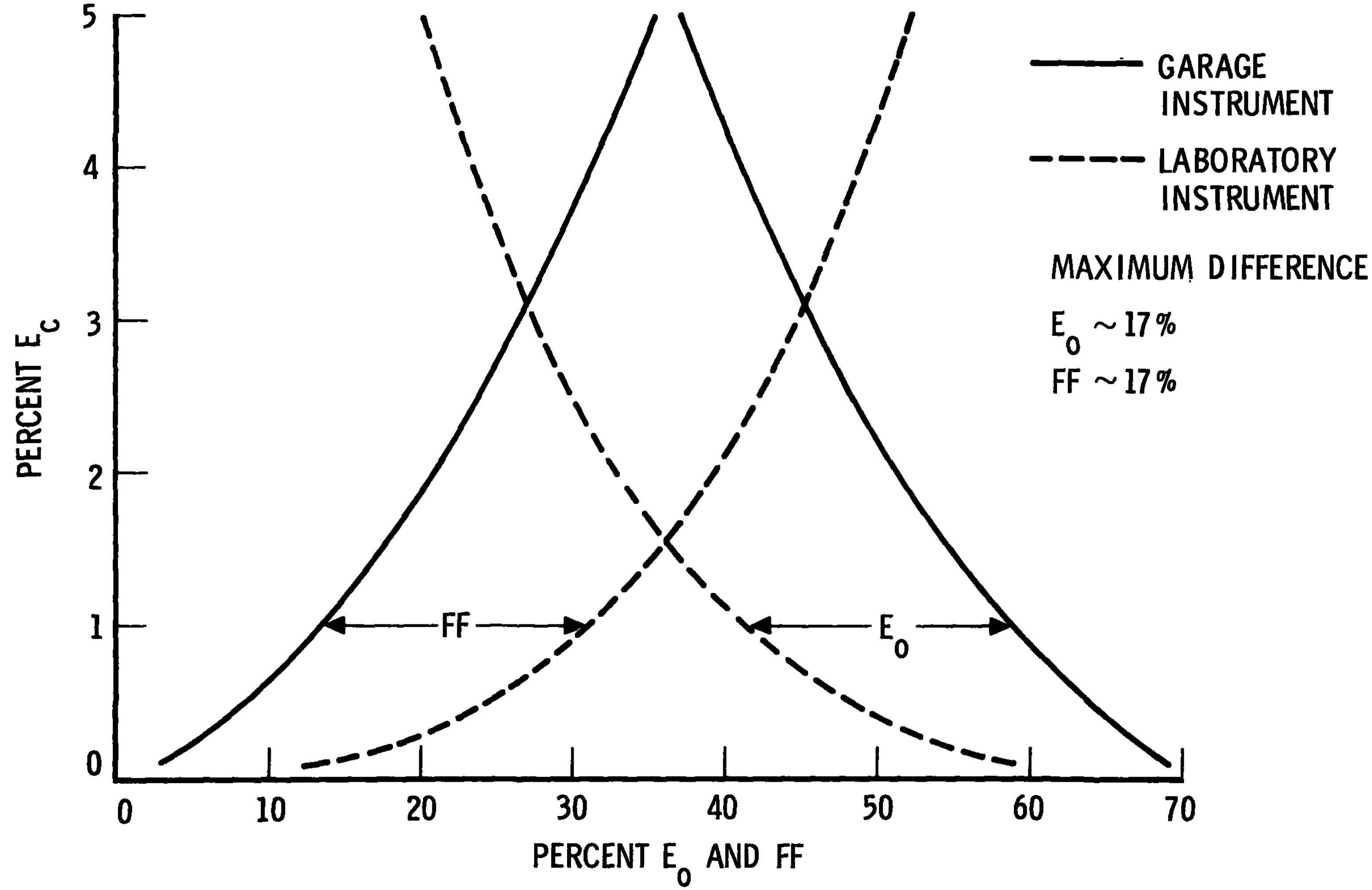


Figure 5-30. Variation of E_C, E_O, and FF with Instrument Type; CO; 1974 Model Year Fleet; Federal Three-Mode Test; Idle Mode; Bounded Errors of Commission Method

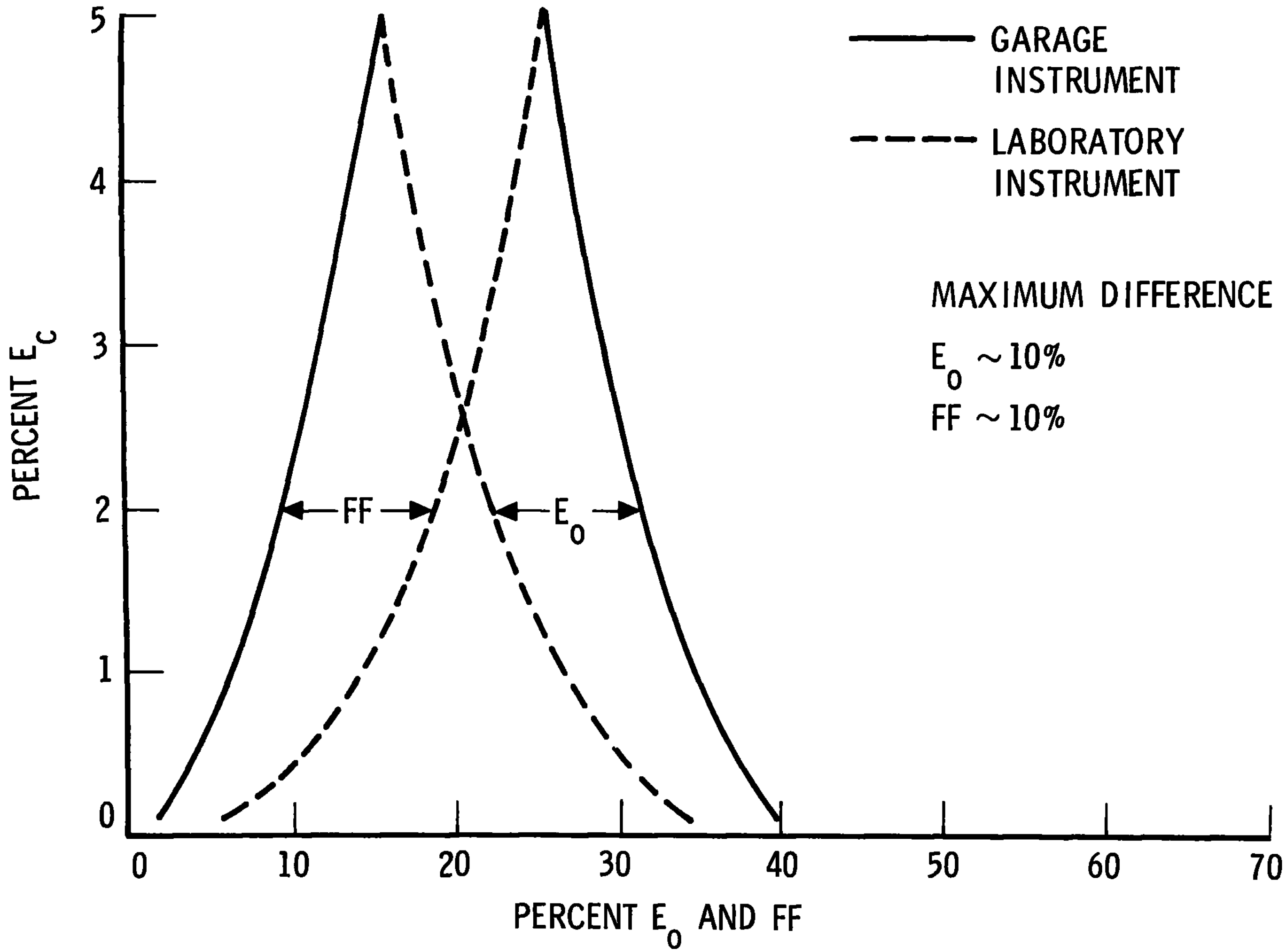


Figure 5-31. Variation of E_c, E_o, and FF with Instrument Type; HC; 1974 Model Year Fleet; Unloaded 2500 rpm Test; Bounded Errors of Commission Method

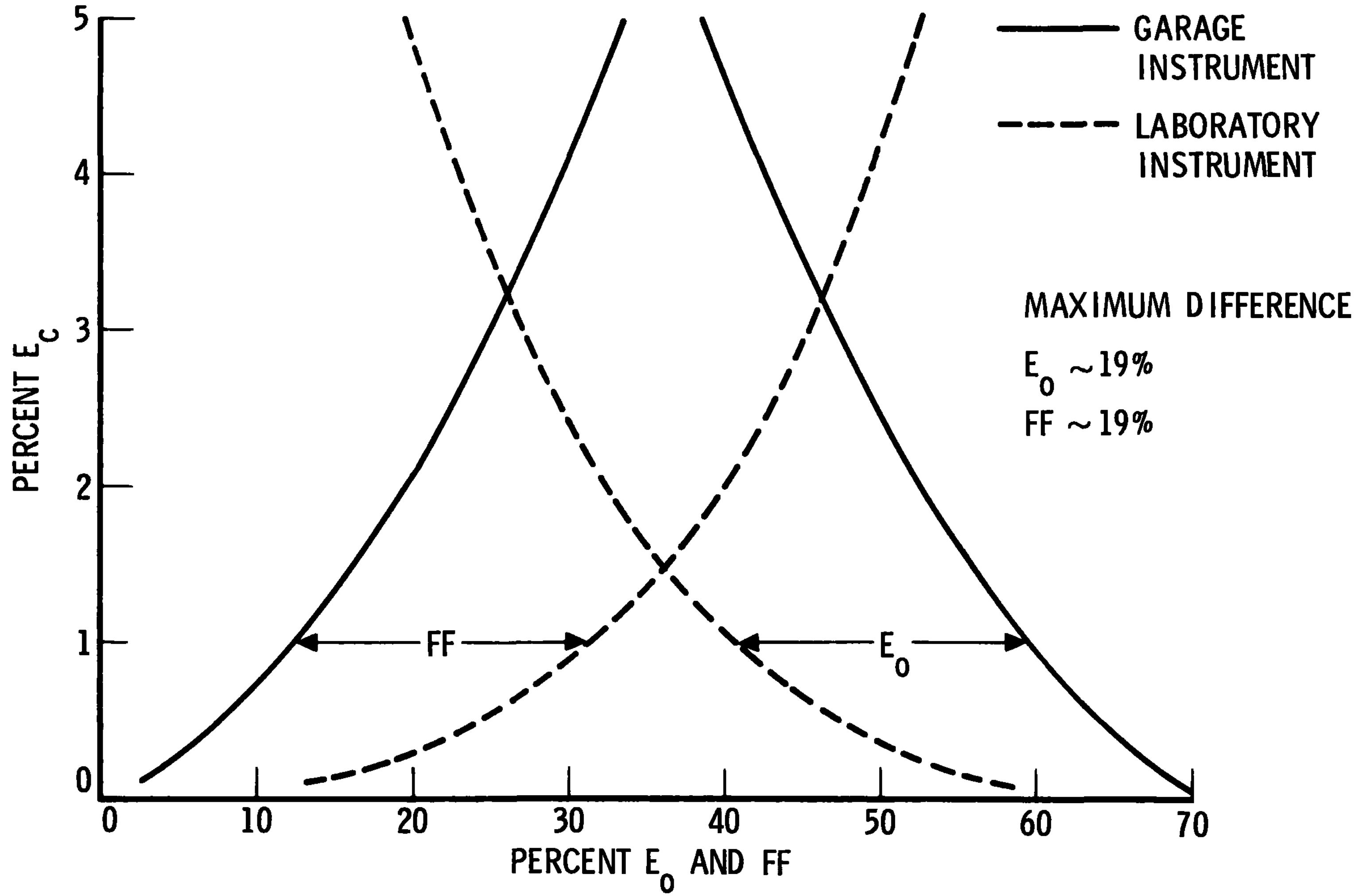


Figure 5-32. Variation of E_C, E_O, and FF with Instrument Type; CO; 1974 Model Year Fleet; Unloaded 2500 rpm Test; Bounded Errors of Commission Method

FTP rejection rate. Thus, the "best" test for fixed percent FF is the one with the lowest percent E_c. In general, the bag-type STs are better in this respect. However, the actual level of percent E_c on the volumetric tests is still quite low. For example, at 30 percent FF on the CO Federal Short Cycle (Figure 5-9), the percent E_c is essentially zero. For CO on the Key Mode low-speed mode, percent E_c is 0.65 percent for laboratory instruments (Figure 5-11) and 3.85 percent for garage instruments (Figure 5-12).

5.2.2.2 Multiple-Constituent Tests

In addition to analyzing each pollutant individually, an analysis was made for multiple-constituent tests. The method of analysis and computational procedures were the same as for the CEV fleet, as discussed in Sec. 4.2.2.5.2.

5.2.2.2.1 Bounded Errors of Commission Results

Three-constituent test results for the Federal Short Cycle and the Federal Three-Mode (high-speed and idle modes only) are displayed in Figures 5-33 through 5-35. Both laboratory and garage instrument results are included. The data plotted are the parametric results. For a detailed discussion of the plot presentation, see Sec. 4.2.2.5.2.1.

5.2.2.2.2 Variance Estimates

Table 5-8 shows the approximate cell standard deviation for a range of cell percentages, assuming N = 147. See Sec. 4.2.2.5.2.2 for a detailed discussion of the approximation procedures.

5.2.2.2.3 Discussion of Results

A comparison of modes on the Federal Three-Mode ST indicates that the idle mode may be more favorable. Using laboratory instruments, the idle mode has fewer errors of commission while maintaining a superior percent FF and percent E_o relation over the high-speed mode for most of the range of predicted percent E_c shown in Figure 5-34. Using garage instruments (Figure 5-35), no statistical difference between the modes is observed.

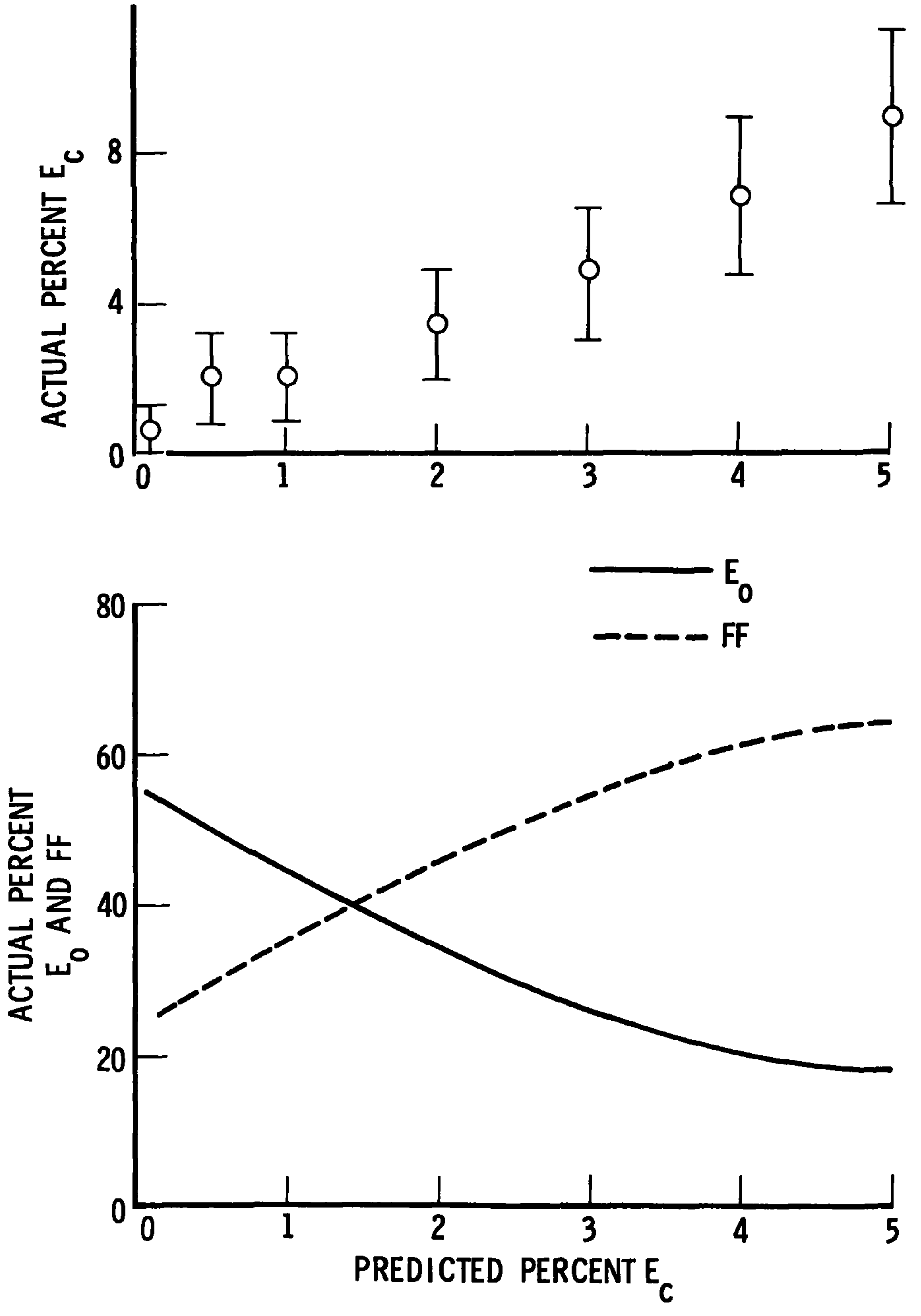


Figure 5-33. Variation of Actual E_c, E_o, and FF with Predicted E_c; Federal Short Cycle; Three-Constituent Test; Bounded Errors of Commission Method; 1974 Model Year Fleet

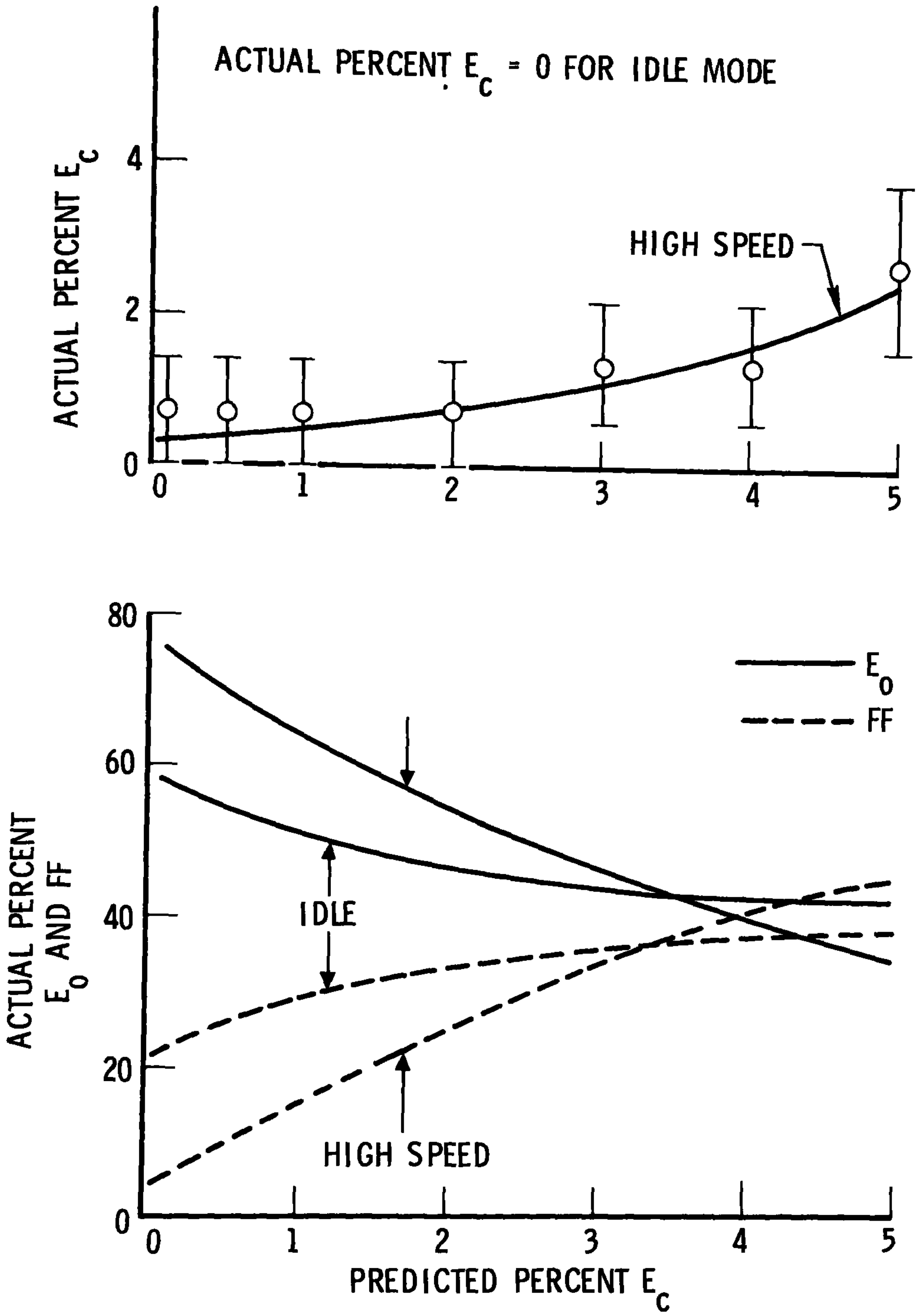


Figure 5-34. Variation of Actual E_c, E_O, and FF with Predicted E_c; Federal Three-Mode; Three-Constituent Test; Laboratory Instruments; Bounded Errors of Commission Method; 1974 Model Year Fleet

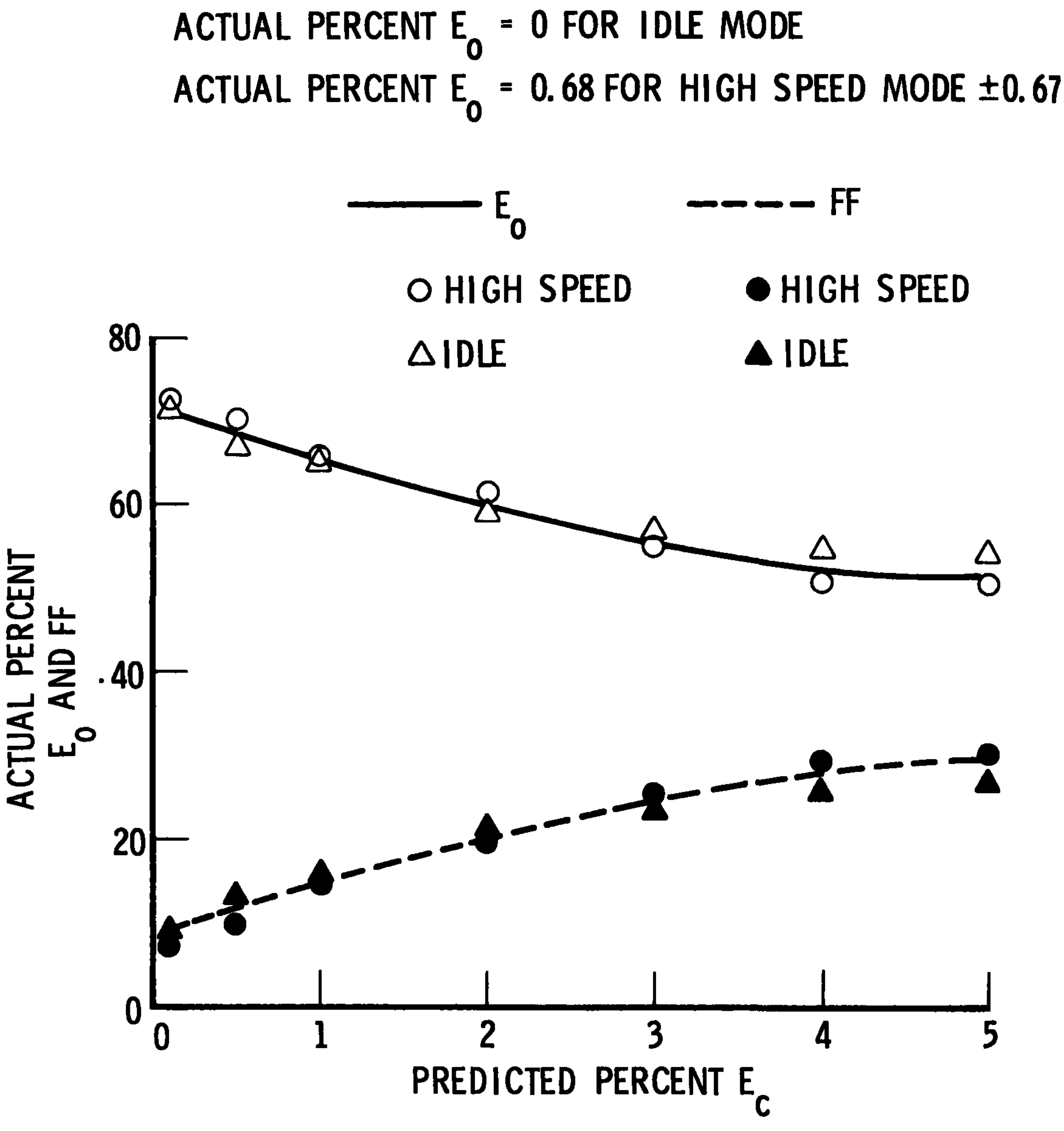


Figure 5-35. Variation of Actual E_c, E_o, and FF with Predicted E_c; Federal Three-Mode; Three-Constituent Test; Garage Instruments; Bounded Errors of Commission Method; 1974 Model Year Fleet

Table 5-8. Standard Deviation for Three-Constituent Tests: 1974 Model Year Fleet, N = 147

Cell Percentage	Cell Standard Deviation, %
60	4.04
50	4.12
40	4.04
30	3.78
20	3.30
10	2.45
5	1.80
3.5	1.52

Comparison of the Federal Short Cycle and the Federal Three-Mode can be made over a limited range of the results. For the actual percent E_c less than 2 percent, the laboratory results of the Federal Three-Mode and the Federal Short Cycle are comparable. Table 5-9 indicates the minimum and maximum for percent FF and percent E_o, while percent E_c is less than 2 percent. There is little difference between the idle mode and the Federal Short Cycle. Over this range of percent E_c, the idle mode would appear favorable to the Federal Short Cycle due to the low value of percent E_c on the idle mode.

A comparison of instrument types shows that the laboratory instruments are generally preferable.

Table 5-9. ST Comparison: 1974 Model Year Fleet; Multiple Constituent Tests ($E_c \leq 2\%$)

Short Test	% FF		% EO	
	Min	Max	Min	Max
Federal Short Cycle	25	36	44	55
Federal Three-Mode:				
Idle	22	38	42	58
High	5	42	38	75

5.3 RELATIVE IMPACT ON AIR QUALITY

5.3.1 By Individual Pollutant

The FTP standards, or cut-points, can be interpreted as establishing the desired impact on air quality in that the FTP cut-points fix the percent of the population classified as high-polluting vehicles. If the FTP were used as the test procedure in an inspection/maintenance program which tested all vehicles (i.e., as the ST), the relative impact on air quality would ideally be 100 percent; that is, all the vehicles that are failures are in fact identified as such.

Similarly, the effectiveness of the various STs can also be used as a measure of impact on air quality, where "ST effectiveness" is defined as:

$$\text{ST effectiveness} = \frac{\text{\% FF for the short test}}{\text{\% FTP failures in same population}} = \frac{\text{\% FF}}{\text{\% FF} + \text{\% } E_o} \qquad (5\text{-}1)$$

Thus, on this basis, the ST is always less effective than the FTP, in proportion to the percent of errors of omission (E_o) associated with a given ST. Table 5-10 shows the ST effectiveness values for the 1974 model year fleet for an E_c rate of 5 percent. These values indicate the relative impact on air quality of the ST as compared with the impact of the FTP on air quality, for the E_c conditions shown.

Actual benefit or impact is dependent upon the user's needs and constraints. One measure of benefit would be the tons of pollutant removed from the atmosphere on an annual basis in a given region by the use of an ST in an inspection/maintenance program. This can be approximated by the relationship:

$$\text{Tons removed} = \text{ST effectiveness} \times \Delta \text{ pollutant to be removed in population} \times \text{\% population sampled} \qquad (5\text{-}2)$$

Table 5-10. Short Test Effectiveness; E_c = 5%
1974 Model Year Fleet

Short Test	ST Effectiveness[a]			%FF		
	HC	CO	NO_x	HC	CO	NO_x
Federal Short Cycle	0.83	0.90	0.17	34	65	3
NY/NJ Composite	0.78	0.88	0.06	32	64	1
Key Mode						
Laboratory	0.58	0.76	0.28	24 (I)[b]	55 (L)	5 (I)
Garage	0.34	0.51		14 (L)	37 (H)	
Federal Three-Mode						
Laboratory	0.61	0.72	0.22	25 (I)	52 (I)	4 (H)
Garage	0.41	0.48		17 (I)	35 (I)	
2500 rpm Unloaded						
Laboratory	0.61	0.73	0.22	25	53	4
Garage	0.39	0.47		16	34	

(a) $\text{ST Effectiveness} = \frac{\bullet\ \%\ \text{FF}}{\text{FTP Fails}}$

where

FTP HC Fails = 41.09%

FTP CO Fails = 72.35%

FTP NO_x Fails = 17.8%

(b) I = idle mode

L = low speed mode

H = high speed mode

where

$$\text{ST effectiveness} = \frac{\%\ FF}{\%\ FF + \%\ E_o}$$

and

Δ pollutant to be removed in population = average value for the population of HC, CO, or NO_x, in tons/year, in excess of that permitted by the FTP standard; it is based on the FTP failures and corresponding emission values observed in the population, and vehicle-miles-traveled characteristics

This relationship ignores those additional benefits likely to occur if the failed vehicles were repaired and achieved emission levels below the FTP standards after repair.

Equation (5-2) indicates areas of tradeoff that should be examined prior to the implementation of a specific inspection/maintenance program. Figure 5-36 depicts one aspect of such tradeoffs. This figure is an illustrative plot of Eq. (5-2) for two different ST (Federal Short Cycle, and Unloaded 2500 rpm with garage instruments) as used for CO emissions. As indicated in Table 5-10, their effectiveness values are 0.90 and 0.47, respectively; i.e., as compared with the CO discrimination capability of the FTP procedure, they are 90 and 47 percent as effective as the FTP in identifying vehicles which fail the FTP test on CO. Thus, to achieve the same benefit in total CO pollutant removal, the percentage of the population that must be sampled by the Unloaded 2500 rpm ST is approximately double that which must be sampled with the Federal Short Cycle ST. Alternatively stated, for any given percent sampling of the population, the use of the Federal Short Cycle ST would result in approximately double the amount of CO removed.

The complexity of program implementation can be measured in annual cost. The cost components would include such items as annual

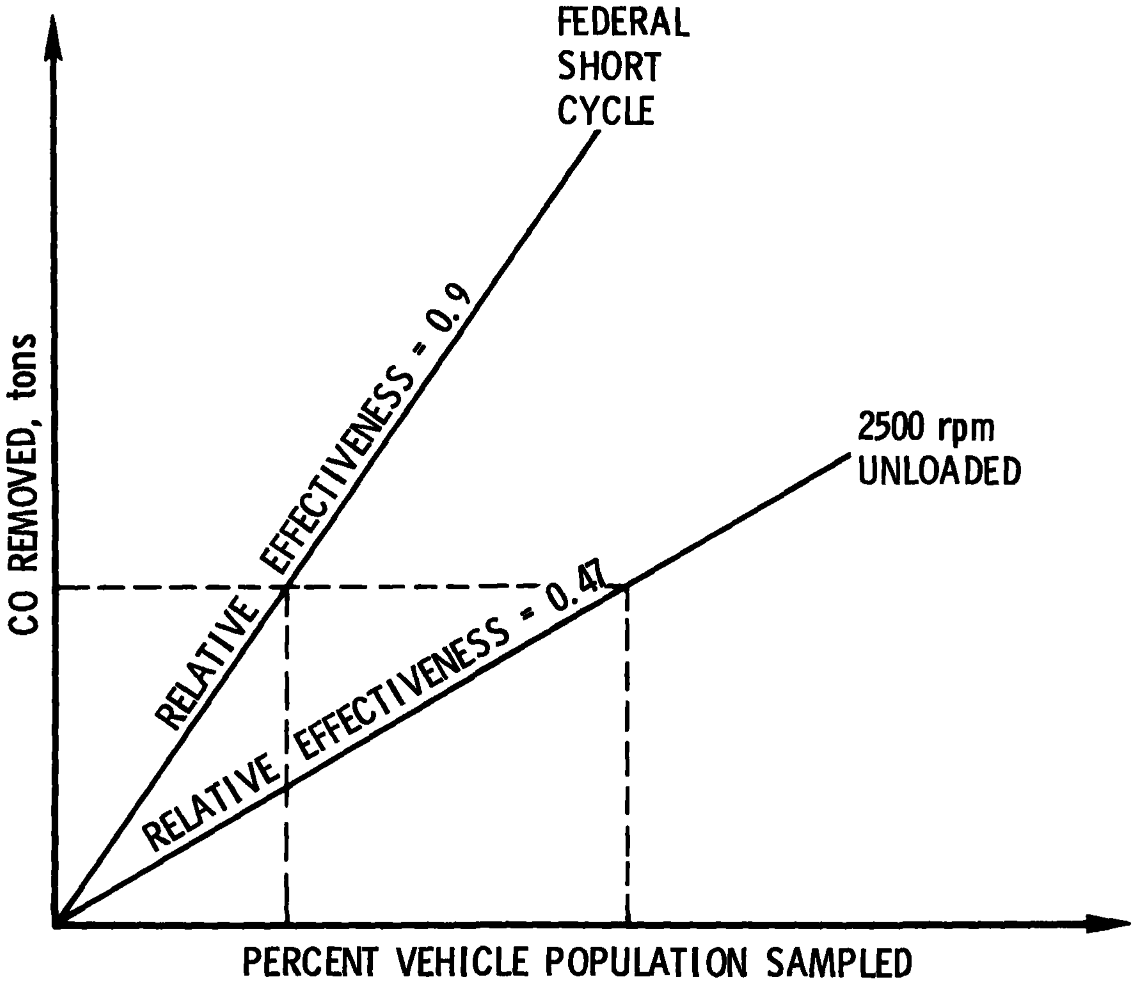


Figure 5-36. Impact of Percent Population Sampled on CO Removed (Illustrative Example Only)

operating expenses, maintenance expenses, and amortized initial development and installation expenses. The ST requiring laboratory instrumentation would have substantial initial procurement costs, and higher annual maintenance and operating expenses than those using garage instruments. The bag-type ST requires more skilled personnel and a CVS station. The bag ST and multi-mode tests also require a dynamometer. Thus, the ST can be ranked according to cost as follows:

- Federal Short Cycle, NJ/NY Composite
- Three-Mode volumetric with laboratory instruments
- Three-Mode volumetric with garage instruments
- 2500 rpm Unloaded with laboratory instruments
- 2500 rpm Unloaded with garage instruments

For those inspection/maintenance programs targeted to 100 percent inspection of all vehicles, the above ranking of ST by cost would appear valid. However, if less than 100 percent inspection is envisioned for some reason, then additional factors should be considered. For example, the unit cost of a program (per vehicle) would be expected to decrease as the percent of the population sampled increases. Thus, in the example of Figure 5-36, if the program were targeted to a defined level of CO removal, a cost-benefit analysis might be an appropriate method to select the ST and the percentage sampled for minimum cost purposes. The type of constraint normally imposed on a tradeoff study would typically be total annual cost; however, additional constraints on percent E_c or percent rejected (E_c plus FF) are also admissible under this approach. Other areas of consideration are effective sampling and site selection, importance of the pollution source as a function of geographic location, social impact, etc.

5.3.2 Multiple Constituent Tests

Short test effectiveness is also a useful measure of test quality for the multiple-constituent test, although the pollutant removal implications of Eq. (5-2) must apply on an individual pollutant basis. Shown in Table 5-11

Table 5-11. Short Test Effectiveness Values for Multiple Constituent Tests; 1974 Model Year Fleet[a]

Short Test	ST Effectiveness	Percent E_c	
		Predicted[b]	Actual
Federal Short Cycle	0.77	5	8.84
	0.373	0.05	2.04
	0.314	0.01	0.68
Federal Three-Mode (Laboratory Instruments)			
Idle	0.483	5	0.00
High	0.568	5	2.72
Federal Three-Mode (Garage Instruments)			
Idle	0.330	5	0.00
High	0.374	5	0.69

[a]FTP failures = 80%

[b]Using bounded errors of commission method of analysis

are the effectiveness values for the Federal Short Cycle and the Federal Three-Mode. Comparison of the test-to-test effectiveness values should, of course, be made at points where the actual percent E_c is equal; however, this can be only approximated with the existing data.

The technical favorability of the Federal Short Cycle is diminished when comparing on the basis of equivalent percent E_c. Although the Federal Short Cycle effectiveness is 0.77 at actual percent E_c equal to 8.84, it is reduced to 0.373 and 0.314 for actual percent E_c values of 2.04 and 0.68, respectively. However, as shown in Table 5-11, the effectiveness values of the high-speed mode of the Federal Three-Mode ST with laboratory and garage instruments are 0.568 (actual percent E_c = 2.72) and 0.374 (actual percent E_c = 0.69), respectively. Comparable effectiveness values for the idle mode with laboratory and garage instruments are 0.483 and 0.330, respectively, both with actual percent E_c equal to 0. Thus, in the actual percent E_c range below approximately 3, the Federal Three-Mode ST with garage instruments (idle or high-speed mode) is essentially equivalent to the Federal Short Cycle in effectiveness while the Federal Three-Mode ST with laboratory instruments has a higher effectiveness than the Federal Short Cycle.

Although the favorability of the laboratory instruments over the garage instruments persists under this method of comparison, consideration of program complexity could bias test desirability in favor of the Federal Three-Mode with garage instruments.

6. DEFECT DATA FROM CATALYST-EQUIPPED EXPERIMENTAL VEHICLE FLEET

6. DEFECT DATA FROM CATALYST-EQUIPPED EXPERIMENTAL VEHICLE FLEET

Upon completion of the FTP and ST tests performed on the CEV fleet as described in Sections 3 and 4, 95 defect tests were performed on 5 of the vehicles from the 40-vehicle CEV fleet.

The 95 defect tests simulated a wide variety of malfunctions that could occur in typical passenger cars. The general categories of defects are defective ignition components, changes in ignition timing, dwell, and spark advance, faulty carburetion, defective valves, clogged air filter, and faulty emission control components. The defects were introduced individually and mixed. The Appendix lists the defect test runs on the five cars. These test data were analyzed to (a) determine the statistical character of the defect tests, and (b) to examine the ability of the STs to detect defective vehicles of this nature. The results are discussed below.

6.1 STATISTICAL ANALYSIS OF DEFECT TESTS

Listed in Table 6-1 are the estimated ST/FTP correlation coefficients for the ungrouped defect data and the original 40-car catalyst-equipped fleet (first good data only), using the method defined in Sec. 4.2.1.1. The HC correlations are consistently higher, over 0.9, among the defect data than the previous 40-car CEV fleet. Addition of all defect data to the original CEV fleet data will significantly distort the population characteristics with regard to HC. CO and NO_x distortion will also occur, although not as pronounced as with HC.

This distortion is also evident when examining elementary statistics. Table 6-2 compares statistics on the FTP data for the two groups. Clearly the data are different and need to be analyzed as distinct groups since the proportion of defect cars to normally operating cars in the true population is unknown.

Table 6-1. ST/FTP Correlation Coefficient Comparison: Defect Test Vehicles vs Original CEV Fleet (laboratory instruments)

Test	N[a]	Pollutant	Correlation Coefficient[b]		Original N[c]
			Defect	Original	
Federal Short Cycle	105	HC	0.962	0.87	39
	105	CO	0.746	0.81	39
	105	NO_x	0.553	0.62	39
NY/NJ Composite	105	HC	0.945	0.91	39
	104	CO	0.721	0.42	39
	105	NO_x	0.740	0.47	39
Key Mode	102	High HC	0.957	0.61	40
	104	CO	0.615	0.26*	40
	105	NO_x	0.905	0.79	40
	103	Low HC	0.964	0.53	40
	103	CO	0.378	0.39	40
	105	NO_x	0.145*	0.20*	40
	98	Idle HC	0.945	0.92	40
	94	CO	0.723	0.54	40
	105	NO_x	0.075*	0.27*	40
Federal Three-Mode	104	High HC	0.959	0.87	31
	105	CO	0.634	0.08	31
	105	NO_x	0.912	0.89	31
	103	Low HC	0.958	0.79	31
	103	CO	0.354	0.22*	31
	103	NO_x	0.268	0.03*	31
	94	Idle HC	0.947	0.80	31
	91	CO	0.743	0.48	31
	105	NO_x	0.277	0.13*	31
2500 rpm Unloaded	101	HC	0.925	0.47	40
	103	CO	0.256	0.30	40
	105	NO_x	-0.048*	0.23*	40

(a) Number of defect tests included in correlation.

(b) The correlation is statistically significant at the 95% confidence level except where indicated by an asterisk.

(c) Number of cars in original CEV fleet.

Table 6-2. Elementary FTP Statistics: Defect Test Vehicles vs Original CEV Fleet (gm/mi)

Pollutant	Defect		Original	
	Mean	Standard Deviation	Mean	Standard Deviation
HC	4.35	6.00	0.64	0.54
CO	10.04	11.81	2.86	1.52
NO_x	3.23	1.42	2.48	0.59

Many of the defect tests are either replications or produce similar data. The defect tests for each car were grouped according to similarity of defect (see Appendix, under the column denoted Group No.). Group No. 1 is the baseline group and represents the normally operating vehicle. A test for a significant difference in the FTP average values of the defect group and the base group was made for each defect group on each car. Defect groups that have no significant difference cannot be statistically distinguished, on the basis of their FTP values, from the baseline group. The defect group contains at least one test distinguishable from normal operation, if there is a significant difference. The distinguishable defect groups were further analyzed for similarity among themselves.

The result of this analysis is a smaller set of defect tests, on each car, that are statistically different from one another. These test data are then taken to represent observations on independent vehicles. Thus, the 95 tests on 5 cars were reduced to approximately 24 defect test observations representing 24 distinct vehicles each with a defect. The results of the analysis are shown in Table 6-3.

Table 6-3. Groups Distinguishable from Baseline Operation: Defect Test Fleet

Car ID	Distinguishable Group No.	Description of Defect
162	4	Lean main fuel system
	6	EGR circuit reduced flow
	8	Valves defective (exhaust)
	9	Valves defective (intake)
	Groups 4 and 9 are statistically similar for Car 162	
164	6	Inefficient catalyst
	7	Inefficient catalyst and 10% misfire
	8	Inefficient catalyst and 5% CO idle
	9	Baseline after leaded fuel use
165	3	Early power circuit activation
	4	No secondary air injection
	6	Rich idle and 10% misfire
	7	No EGR and 6° timing advance
	8	Reduced secondary air and oversize fuel jets
	Groups 4 and 8 are statistically similar for Car 165	
169	2	Timing under-advanced
	3	Timing over-advanced
	8	Rich idle and no secondary air
	9	Rich idle and PCV closed
	10	Defective spark plug
170	3	Rich idle 8% CO
	4	10% intermittent misfire
	5	3% intermittent misfire
	6	No EGR
	8	10% misfire and rich idle
	9	10% misfire and lean idle
	10	10% misfire and no EGR
	11	Rich idle and no EGR
	14	Rich idle and rich main
	Groups 6 and 11 are statistically similar for Car 170	

6.1.1 Data Selection Procedures

The statistical procedure used to test for differences between groups was a multivariate linear hypothesis test.* The likelihood ratio statistic which has an equivalent F-statistic was used to make the test of significance at the 95% level. The analysis was conducted on the FTP data, as these are most representative of the true state of the vehicle. The conclusion of this analysis is shown in Table 6-3.

To establish a data base for further analysis, actual data from the individual groups were selected according to the following rules:

a. One run (testing sequence) may be selected from each distinguishable group. If distinguishable groups are similar, only one run may be selected from the similar groups.

b. Run preferences are:

   1. More acceptable ST data
   2. Less ambiguity in the run
   3. Lowest run number

As the assumption of independence of the observations is crucial to contingency table analysis, the 95 defect tests were statistically pruned to 24 tests representing 24 independent defective vehicles. These data are considered to represent a population distinct from the original 40-car population. Of these 24, 6 have no Federal Three-Mode (laboratory) data and 5 have no Key Mode (laboratory) data.

*T. W. Anderson, An Introduction to Multivariate Statistical Analysis, John Wiley and Sons, Inc., New York (1958).

6.2 CONTINGENCY TABLE ANALYSIS OF DEFECT DATA

The analysis proceeded in two stages. The original CEV fleet population was first analyzed, using first good data. The analysis method was the bounded errors of commission procedure, which established the ST cut-points (see Sec. 4.2.2.1.2). Percent E_c was varied from 10% to 1% in 1% increments, with the addition of points at 0.5% and 0.1%. Immediately following analysis of the original CEV fleet, the defect population was analyzed. The contingency table results were calculated for this population, using the cut-points previously determined from the original CEV fleet population. The computations were performed at each of the E_c settings. Thus the analysis is merely an assessment of how well a test constructed using an unknown mix of normal and defect operation data will perform on a population of defective vehicles known to represent extreme departures from normal operation.

A summary of the analysis on each constituent is given in Table 6-4. The ST cut-points were established for E_c less than or equal to 5%, and the FTP level was level I (HC = 0.41 gm/mi, CO = 3.4 gm/mi, NO_x = 3.1 gm/mi).

Sample plots are shown in Figures 6-1 through 6-6 for the Clayton Key Mode (laboratory data). Comparing Figures 6-1 and 6-2, which represent the analysis for HC, at E_c equal to 0.1%, the original fleet has approximately 33% E_o, and 35% FF. The defect data show E_c at 5%, E_o at 8%, and FF at 66%. As the loci of Figure 6-2 are relatively flat, the defect discrimination qualities of the Key Mode on HC appear virtually insensitive to policy decisions of 10% E_c or less.

The results of three- and nine-constituent tests for the Key Mode (laboratory) are shown in Table 6-5. These results are typical for all the multi-constituent tests.

Table 6-4. Defect Analysis Comparison Summary: Predicted Population [% E_c = 5[(a)], FTP Level I[(b)]]

Short Test	Test Mode	No. of Defect Cars	Pollutant	Original CEV Fleet		Defect Fleet		
				% E_o	% FF	% E_o	% FF	% E_c
Federal Short Cycle		24	HC	11.0	55.9	5.40	69.0	4.21
			CO	14.1	22.1	6.28	65.2	6.11
			NO_x	9.60	5.36	36.6	16.9	1.22
NY/NJ Composite		24	HC	7.24	59.6	5.31	69.1	6.02
			CO	16.1	20.1	7.85	63.4	9.3
			NO_x	9.77	5.19	18.4	35.19	10.5
Key Mode (Laboratory)	High	19	HC	30.4	36.8	6.47	67.6	2.84
			CO	36.0	7.75	22.2	48.3	11.4
			NO_x	6.87	8.69	8.55	52.2	9.31
	Low		HC	35.3	37.0	6.36	67.7	2.42
			CO	33.0	10.8	17.2	53.2	13.8
			NO_x	13.8	1.76	45.0	15.8	11.3
	Idle		HC	6.79	60.5	6.01	68.1	5.56
			CO	28.6	15.2	10.8	59.7	6.26
			NO_x	13.4	2.20	45.4	15.4	8.34
Key Mode (Garage)	High	24	HC	21.8	45.4	8.02	66.4	3.63
			CO	33.3	10.1	23.9	47.4	12.03
	Low		HC	22.3	44.9	8.16	66.3	5.37
			CO	36.5	6.79	32.0	39.3	16.5
	Idle		HC	10.38	56.8	8.03	66.4	8.68
			CO	29.2	14.1	11.7	59.6	7.29
Federal Three-Mode (Laboratory)	High	18	HC	10.8	58.1	9.85	71.6	4.74
			CO	43.5	6.10	16.14	52.4	7.48
			NO_x	2.93	8.75	5.65	53.6	6.05
	Low		HC	16 9	52.0	10.6	70.8	4.54
			CO	40.9	8.68	20.1	48.5	10.1
			NO_x	10.9	6.73	50.5	8.78	2.30
	Idle		HC	16.6	52.3	10.5	70.9	6.55
			CO	33.4	16.1	17.0	51.6	10.6
			NO_x	10.6	1.05	54.1	5.17	0.88
Federal Three-Mode (Garage)	High	24	HC	19.5	47.7	8.47	66.0	3.75
			CO	36.1	7.21	23.6	47.7	11.6
	Low		HC	22.0	45.2	8.16	65 8	5.16
			CO	36.5	6.81	30.6	40.7	13.7
	Idle		HC	18.0	49.1	6.81	67.6	6.13
			CO	29.2	14.1	12.9	58.4	4.48
2500 rpm Unloaded (Laboratory)		24	HC	38.7	28.5	13.7	60.7	0.97
			CO	34.9	8.46	21.0	50.4	10.3
			NO_x	12.9	1.83	47.7	5.93	2.26
2500 rpm Unloaded (Garage)		24	HC	37.0	30.2	15.0	59.5	1.55
			CO	37.7	5.62	39.9	31.37	8.74

(a) E_c 5% constant for original CEV fleet

(b) HC 0.41 gm/mi
CO 3.4 gm/mi
NO_x 3.1 gm/mi

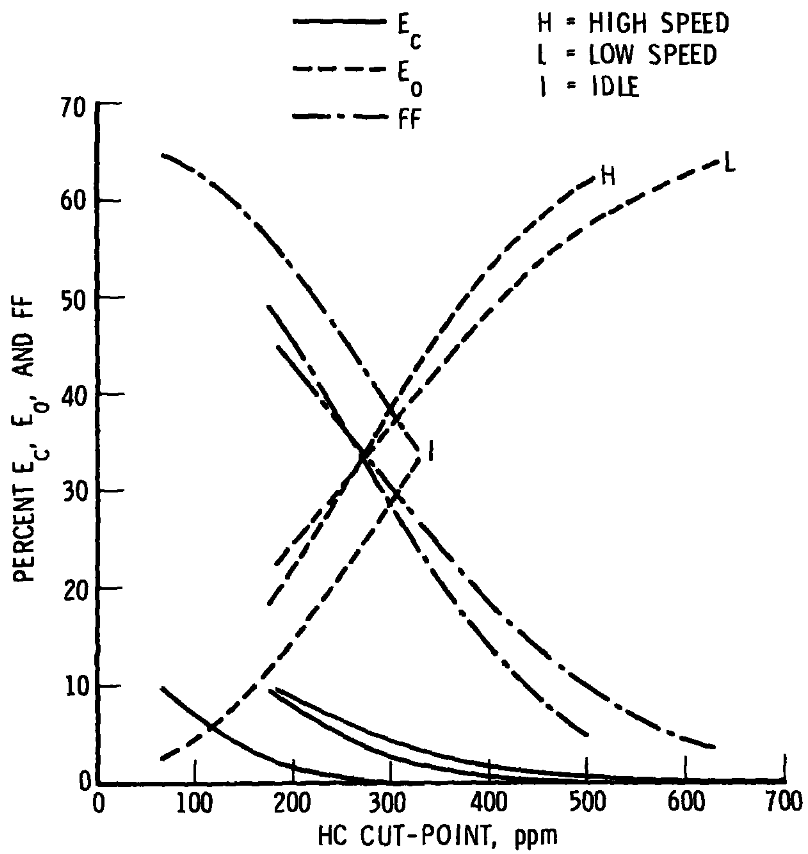


Figure 6-1. Variation of E_c, E_o, and FF with HC Cut-point; Original CEV Fleet; Key Mode Test; 1975 FTP Level = 0.41 gm/mi; Bounded Errors of Commission Method

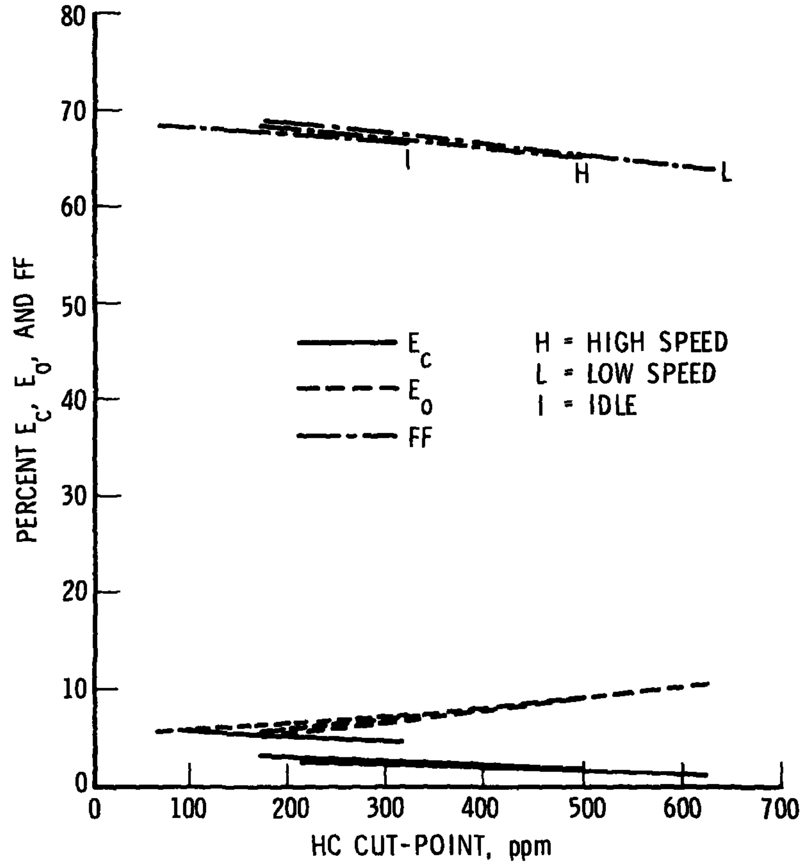


Figure 6-2. Variation of E_c, E_o, and FF with HC Cut-point; Defect Tests Only; Key Mode Test; 1975 FTP Level = 0.41 gm/mi; Bounded Errors of Commission Method

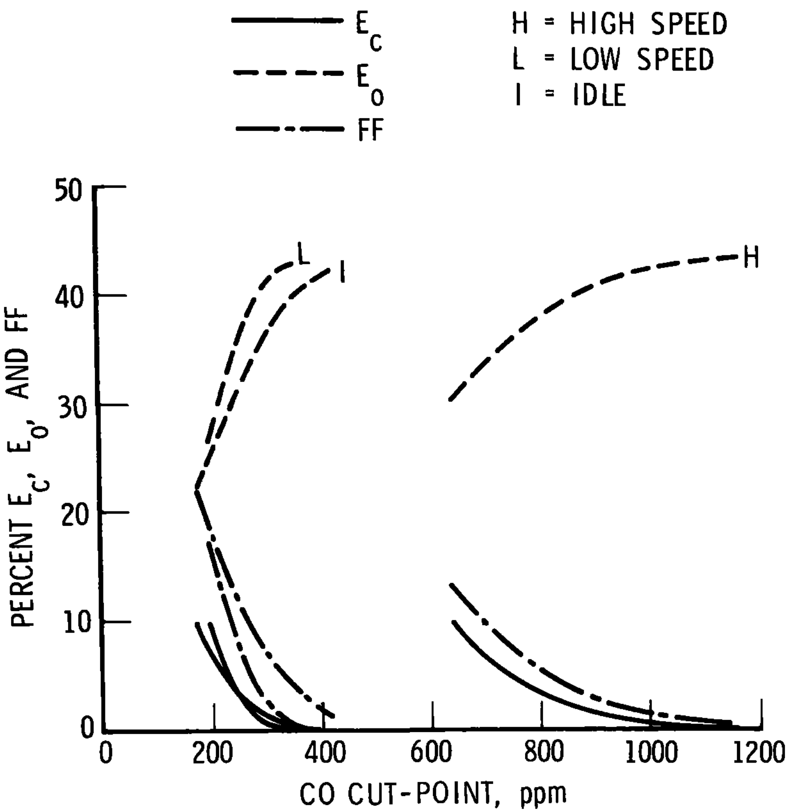


Figure 6-3. Variation of Ec, Eo, and FF with CO Cut-point; Original CEV Fleet; Key Mode Test; 1975 FTP Level = 3.4 gm/mi; Bounded Errors of Commission Method

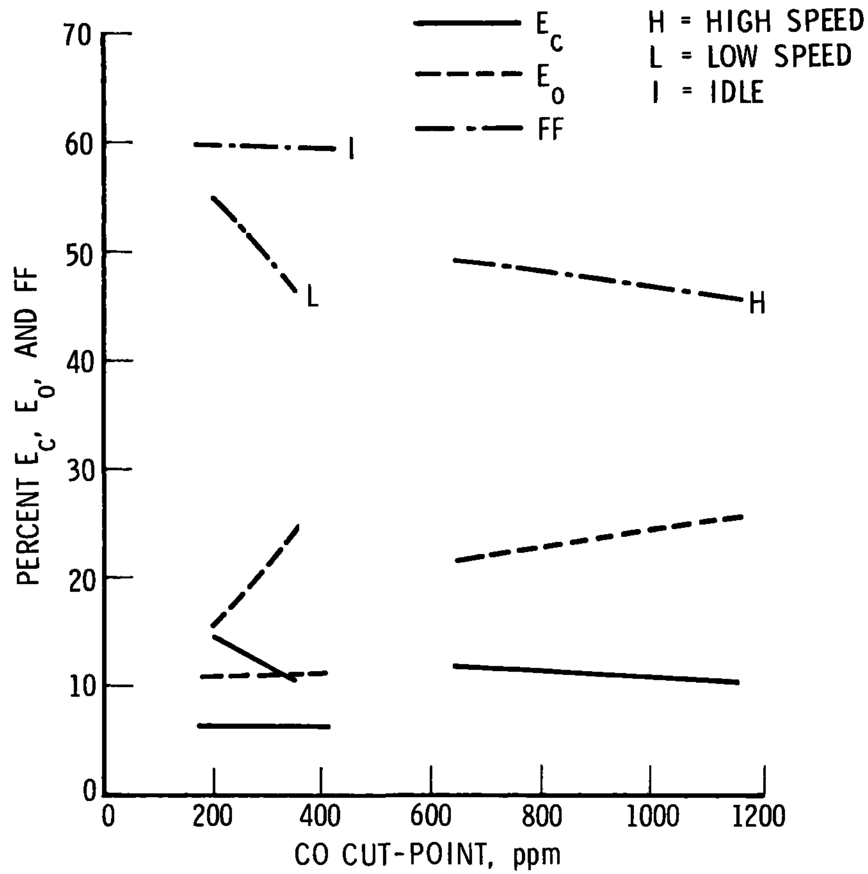


Figure 6-4. Variation of E_c, E_o, and FF with CO Cut-point; Defect Tests Only; Key Mode Test; 1975 FTP Level = 3.4 gm/mi; Bounded Errors of Commission Method

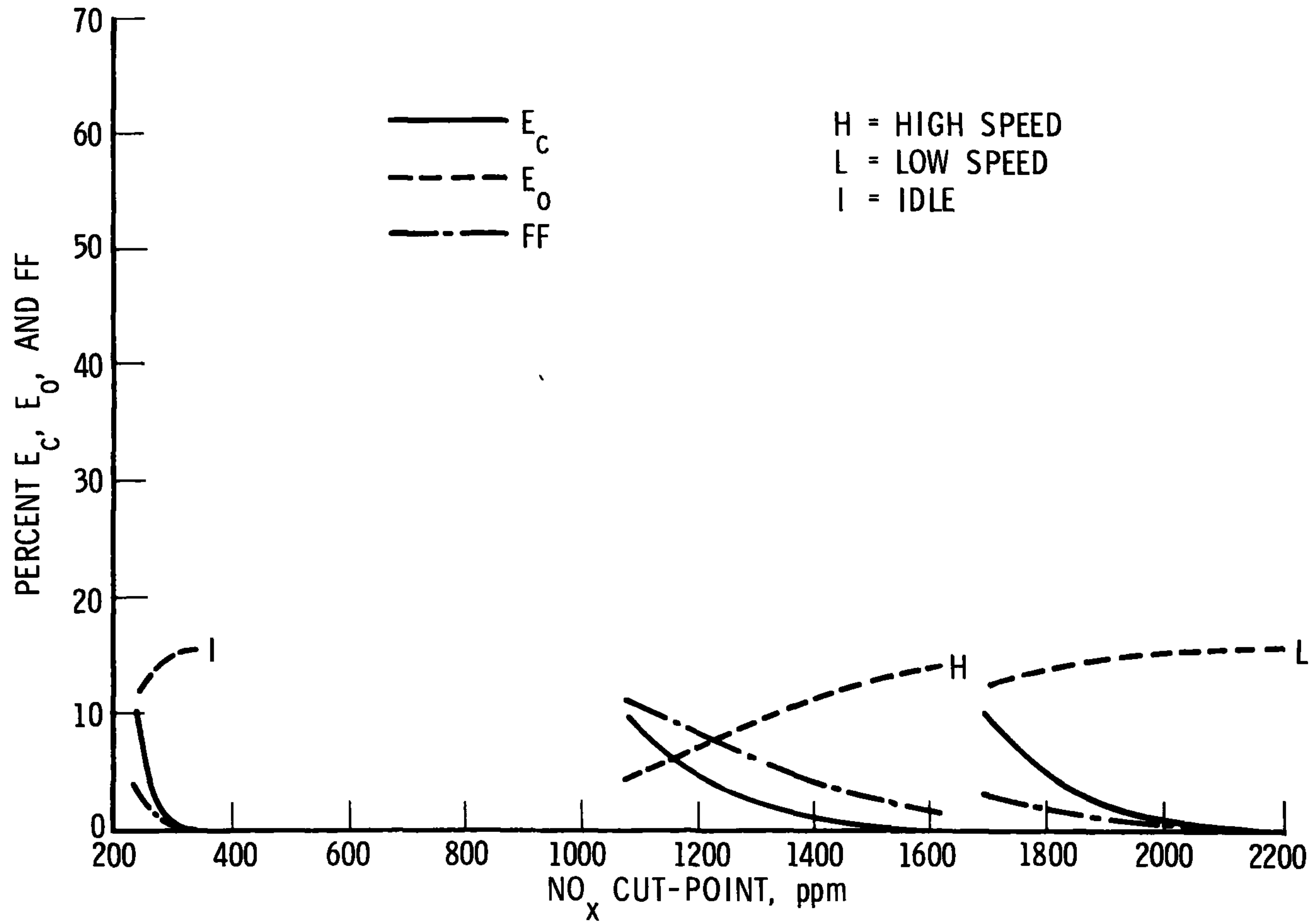


Figure 6-5. Variation of E_c, E_o, and FF with NO_x Cut-point; Original CEV Fleet; Key Mode Test; 1975 FTP Level = 3.1 gm/mi; Bounded Errors of Commission Method

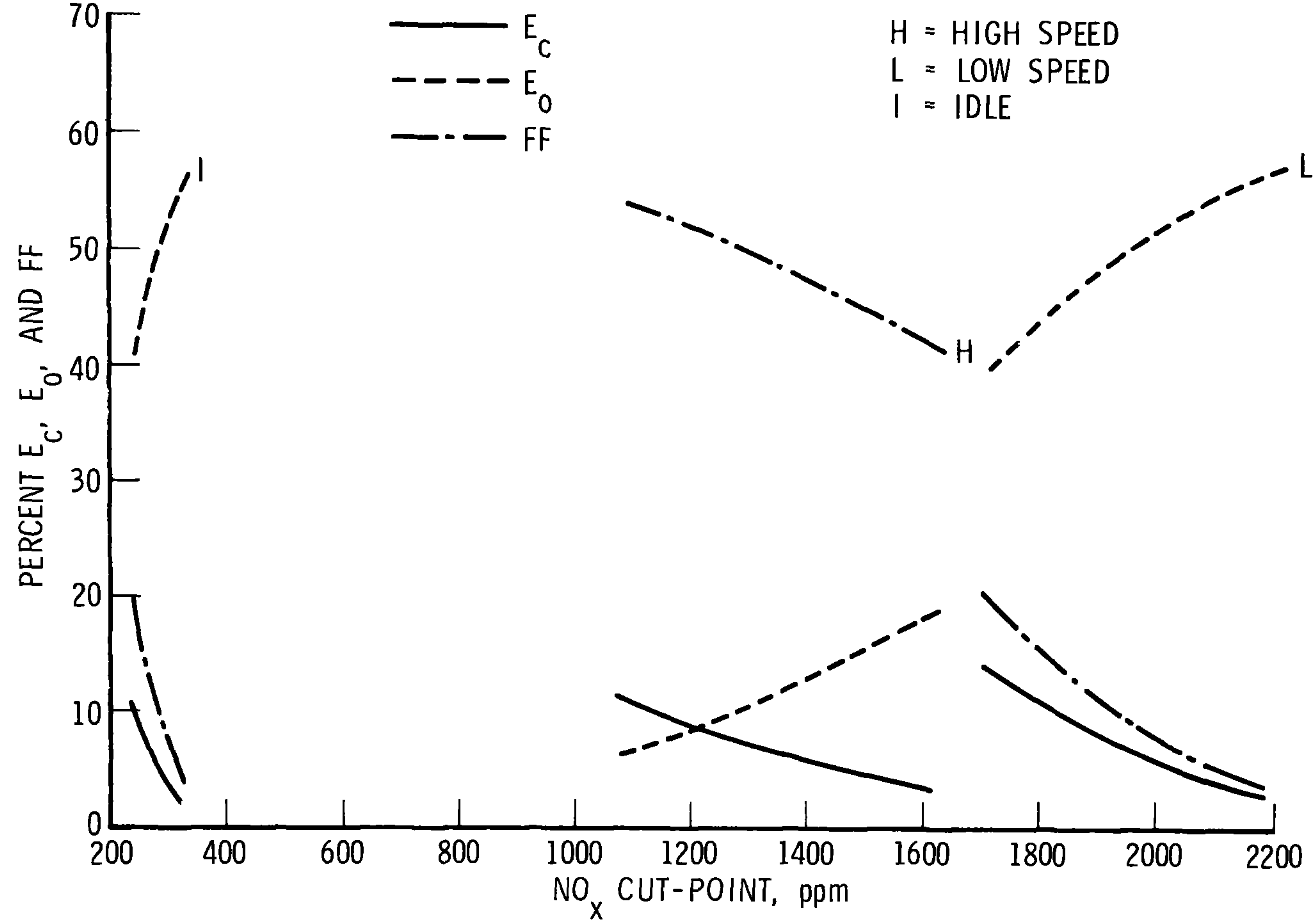


Figure 6-6. Variation of E_c, E_o, and FF with NO_x Cut-point; Defect Tests Only; Key Mode Test; 1975 FTP Level = 3.1 gm/mi; Bounded Errors of Commission Method

Table 6-5. Key Mode Composite Test[a] (laboratory data)

Test Type	Original CEV Fleet			Defect Fleet		
	% FF	% E_c	% E_o	% FF	% E_c	% E_o
Three-constituent:						
High Speed	27.5	5.00	37.5	89.5	0	10.5
Low Speed	22.5	5.00	42.5	73.7	0	26.3
Idle	60.0	5.00	5.00	89.5	0	10.5
Nine-constituent	62.5	12.50	2.50	94.7	0	5.26

[a] % $E_c \leq 5$; FTP Level I (HC = 0.41 gm/mi, CO = 3.4 gm/mi, NO_x = 3.1 gm/mi)

6.3 CONCLUSIONS

A review of the typical results illustrates that the short tests perform well at isolating a population of defective cars. This is noted by the general tendency for percent FF to increase and percent E_o to decrease in the defect population. Although percent E_c decreased for HC, this was not generally true for CO and NO_x.

The sources of the errors of commission and omission are two-fold. The first and usual source is that of the test procedures, i.e., measurement errors. The second source is due to mixing of defects. An observation was classified as a defective car if any component of this vehicle was defective. Hence, all the NO_x data analyzed are not representative of NO_x defects, for example. The multiple-constituent tests (which tend to eliminate mixing errors), show a very high probability, greater than 70%, of detecting defect vehicles (note that all the defective cars failed the FTP at Level I).

In conclusion, the ST/FTP tracking of defective vehicles is very good.

APPENDIX

DEFECT TEST DESCRIPTIONS

Table A-1. Defect Vehicle Test Schedule and Defect Description

Step No.	Type of Defect	Car Setup Procedure	Number of Tests This Step	Group No.	Olson Labs Run Number
		Car 1754162			
1	Baseline	Check CO, timing, dwell, etc., and record. Perform one baseline test on the vehicle.	1	1	(A07752)[1] A07905
2	Idle system lean	Lean idle system to either 0.5% CO before catalyst with secondary air disconnected or 100-rpm drop lean from lean best idle. Do not allow excessive misfire, however.	2	2	A07947 A07961
3	Baseline	Return idle setting to original setting.	0		
4	Idle system low rpm	Decrease idle rpm 75 to 100 rpm while holding all other parameters at manufacturer's specifications.	2	3	A07974 A07984
5	Idle	Decrease idle rpm by 150 rpm, providing misfire is not encountered.	1*	3	A08125X
6	Baseline	Return car to original setting.	0		
7	Lean main fuel system	Install main fuel jets that are two sizes (0.002 in.) smaller than original fuel jets. Fuel float level remains same as with original jets.	2	4	A08141 A08172
8	Baseline	Remove jets and reinstall original jets. Run one baseline test.	1	1	A08191
9	Carburetor power circuit	Disable carburetor power circuit so that the vehicle receives no power circuit operation.	2	5	A08242 A08254
10	Baseline	Return vehicle to original condition by reactivating power circuit.	0		
11	EGR circuit reduced flow	Reduce EGR flow in EGR circuit by approximately 50% by blocking EGR tube to carburetor baseplate.	2	6	A08260 A08264X
12	Baseline	Restore full EGR flow and return vehicle to original condition.	0		

1 = Baseline replicate
* = Tests that require temperature and flow measurements
X = Runs with temperature and flow measurements

Table A-1. Defect Vehicle Test Schedule and Defect Description (Continued)

Step No.	Type of Defect	Car Setup Procedure	Number of Tests This Step	Group No.	Olson Labs Run Number
		Car 1754162 (Continued)			
13	Fuel pump low	Reduce fuel pump pressure by 25% and test vehicle once.	1*	7	A08278X
14	Baseline	Restore full fuel pump pressure and run one baseline test.	1	1	A08293
15	Valves defective	Remove cylinder head from vehicle. Obtain one replacement exhaust valve from a Ford dealer and cut a wedge in the face of the valve which has an area removed corresponding to 5 to 10% of the total valve face area. Install valve in the front cylinder and reinstall head. Maintain the same valve lash as for the original valve removed.	2	8	A08371 A08377
16	Valves defective intake	Remove cylinder head and defective exhaust valve. Obtain the corresponding intake valve for this vehicle and also take a wedge of 5 to 10% of the total valve face from the intake valve. Install the front cylinder. Install original nondefective exhaust valve.	2	9	A08431 A08445
17	Baseline	Remove cylinder head and defective valve. Reinstall original valve. Run one baseline test.	1*	1	A08477X
		Car 2104164			
1	Baseline	Check CO, timing, dwell, etc., and record. Perform one baseline test on the vehicle.	1	1	(A07751)[1] A07812
2	Advanced basic ignition timing	Using a distributor with vacuum and centrifugal advance characteristics representative of the five cars under test, advance the idle timing by 6° (not to exceed audible knock during first large acceleration on FTP when engine is hot).	2	2	A07950 A07960
3	Baseline	Return timing to original setting.	0		
4	Insufficient secondary air	Modify the secondary air supply system (larger pulley, air leak, etc.) so as to obtain approximately a 50% reduction in secondary air injection.	2	3	A07972 A07983

1 = Baseline replicate
* = Tests that require temperature and flow measurements
X = Runs with temperature and flow measurements

Table A-1. Defect Vehicle Test Schedule and Defect Description (Continued)

Step No.	Type of Defect	Car Setup Procedure	Number of Tests This Step	Group No.	Olson Labs Run Number
		Car 2104164 (Continued)			
5	Baseline	Return secondary air injection system to normal.	0		
6	Over-rich main fuel system	Install main fuel jets that are three sizes (0.003 in.) larger than original fuel jets, e.g., 47F to 50F jet sizes. Fuel float level remains as previously set.	2	4	A07918 A08051
7	Baseline	Return main fuel jets to original size.	0		
8	High rpm idle	Increase engine idle speed by 150 rpm to approximately 800 rpm. All other parameters remain as at lower idle speed.	1	5	A08066
9	High rpm idle	Increase engine idle speed by 75 to 100 rpm to between 725 and 750 rpm.	2	5	A08101X A08110X
10	Baseline	Set all parameters to original baseline levels and test.	1	1	A08128
11	Inefficient catalyst	Drain the zero-lead fuel from the vehicle and refuel with leaded regular gasoline. Operate the vehicle so as to consume the tank of gasoline. Replenish the gasoline supply and test the vehicle once. Remove the leaded fuel and replace with unleaded (30% of tank volume). Repeat the test. Fill the vehicle with leaded fuel. Test again.	3	6	A08155 A08170 A08183
		Note: The following tests contain two or more defects:			
12	Inefficient catalyst plus intermittent misfire	With the catalyst operating inefficiently, as in step No. 11, introduce a 10% intermittent misfire rate and test on leaded fuel.	2*	7	A08214X A08231X
13	Inefficient catalyst plus rich idle	Set idle CO at 5% (without secondary air). Ignition system operating normally. Test using leaded fuel. Return all components to normal and operate the car on unleaded fuel at high loads and speed so as to reactivate the catalyst.	1*	8	A08253X

* = Tests that require temperature and flow measurements
X = Runs with temperature and flow measurements

Table A-1. Defect Vehicle Test Schedule and Defect Description (Continued)

Step No.	Type of Defect	Car Setup Procedure	Number of Tests This Step	Group No.	Olson Labs Run Number
		Car 2104164 (Continued)			
14	Baseline	Test the car on unleaded fuel. If the emissions have returned to the original baseline level, proceed with the next step. If the emissions have not returned to "normal," operate for one additional tank of unleaded fuel. If the emissions have still not normalized, the remainder of this vehicle's tests will be performed on another vehicle.	2	9	A08259 A08279
		Car 2364165			
1	Baseline	Check CO, timing, dwell, etc., and record. Perform one baseline test on the vehicle.	1	1	(A07906)[1] A07934
2	Retarded timing (basic)	Using a distributor with vacuum and centrifugal advance characteristics representative of the five cars under test, retard the idle timing by 6°.	2	2	A07948 A07963
3	Baseline	Return car to original condition.	0		
4	Early power circuit activation	Search the Ford Motor Company parts specifications and determine the power value part number that is designed to "come in" soonest, i.e., about 10 in. Install this part in the carburetor.	2	3	A08003 A08052
5	Baseline	Return car to original condition.	0		
6	No secondary air injection	Deactivate the secondary air injection system.	2*	4	A08100X[2] A08180X
7	Baseline	Return car to original condition.	0		
8	Timing over-advancing (vacuum)	Modify the vacuum advance mechanism so as to give early advancing without impacting the maximum advance obtained. Modify so as to obtain the same advance at 10 in. as would normally be obtained at 15 in.	2	5	A08193 A08215
9	Baseline	Return the car to original condition.	1	1	A08230

1 = Baseline replicate
2 = No cat bed roll
* = Tests that require temperature and flow measurements
X = Runs with temperature and flow measurements

Table A-1. Defect Vehicle Test Schedule and Defect Description (Continued)

Step No.	Type of Defect	Car Setup Procedure	Number of Tests This Step	Group No.	Olson Labs Run Number
		Car 2364165 (Continued)			
		Note: The following tests contain two or more common defects:			
10	Rich idle plus intermittent misfire of spark plugs	Richen idle system to either 5% CO before catalyst with secondary air disconnected or 100 rpm drop rich from lean best idle plus introduce intermittent misfire at a 10% misfire rate.	1	6	A08240X
11	Baseline	Return the car to original condition.	0		
12	EGR not working plus ignition timing advanced	Deactivate EGR system plus advance the idle timing by 6° (no audible knocks).	2	7	A08256 A08258
13	Baseline	Return the car to original condition. Run one baseline test.	1	1	A08267
14	Reduced flow from secondary air system plus over-rich main fuel system	Modify secondary air supply system to obtain approximately a 50% reduction in secondary air injection plus install main fuel jets that are three sizes larger than original fuel jets.	2	8	A08295 A08307
15	Reduced secondary air flow plus lean main fuel system	Remove oversize jets and install undersize jets (two sizes smaller) and retest with reduced secondary air flow (reduction same as step No. 14).	1	9	A08320
16	Baseline	Return the car to original condition.	0		
17	Retarded ignition timing plus high idle rpm	Increase idle by 100 rpm and retard idle basic timing by 6°.	1	10	A08432
18	Baseline	Return the car to original condition. Run one baseline test.	1	1	A08444

X = Runs with temperature and flow measurements

Table A-1. Defect Vehicle Test Schedule and Defect Description (Continued)

Step No.	Type of Defect	Car Setup Procedure	Number of Tests This Step	Group No.	Olson Labs Run Number
		Car 2544169			
1	Baseline	Check CO, timing, dwell, etc., and record. Perform one baseline test on the vehicle.	1	1	(A07922)[1] A07935
2	Timing under-advancing (vacuum)	Modify the vacuum advance mechanism so as to give late advancing without impacting the maximum advance obtained. Modify so as to obtain the same advance at 10 in. as would be obtained at 5 in.	2	2	A07973 A07987
3	Baseline	Return car to original condition.	0		
4	Timing over-advancing (centrifugal)	Modify the centrifugal advance mechanics so as to give early advancing without impacting the vacuum advance circuit and without increasing the maximum centrifugal advance possible. Modify so as to obtain the same advance at 1500 rpm (distributor) as would be obtained at 2000 rpm normally.	2	3	A08020 A08050
5	Baseline	Return car to original condition.	0		
6	Timing under-advancing (centrifugal)	Modify the centrifugal advance mechanism so as to give late advancing without impacting the vacuum advance circuit or the maximum amount of centrifugal advance. Modify so as to obtain the same advance at 2000 rpm (distributor) as would be obtained at 1500 rpm normally.	2	4	A08065 A08083
7	Baseline	Return car to original condition. Perform one baseline test.	1	1	A08124
8	Vacuum line leaking	Remove one of the non-emission control device vacuum lines from the "Christmas tree." Meter if necessary to prevent excessive lean misfire which could cause engine stalling.	2	5	A08132 A08140
9	Baseline	Return car to original condition.	0		
10	PCV valve stuck closed	Remove PCV valve and plug PCV line, allowing no positive crankcase ventilation.	1	6	A08182

1 = Baseline replicate

Table A-1. Defect Vehicle Test Schedule and Defect Description (Continued)

Step No.	Type of Defect	Car Setup Procedure	Number of Tests This Step	Group No.	Olson Labs Run Number
		Car 2544169 (Continued)			
11	PCV valve stuck open	Remove blockage in PCV line and reconnect with PCV valve in circuit but locked open.	1	7	A08192
12	Baseline	Return to original condition by reinstalling good PCV valve.	0		
13	Vacuum spark disconnect not working	If the vehicle is equipped with a vacuum spark disconnect circuit, render it inoperative.	Defect not available		
14	Baseline	Restore VSD circuit and return to original condition. Perform one baseline test.	1	1	A08217
		Note: The following tests (steps 15 through 18) contain two or more defects:			
15	Idle system too rich plus secondary air disconnected	Richen idle system to 5% CO before catalyst with secondary air disconnected.	1*	8	A08241X
16	Idle system too rich plus vacuum spark disconnect not working	With idle CO at 5% CO, disconnect vacuum spark disconnect circuit (secondary air system in operation during testing).	Defect not available		
17	Idle system too rich plus PCV valve blocked	With idle CO at 5%, plug PCV system so that there is no flow into the intake manifold.	1*	9	A08266X
18	Baseline	Return vehicle to original condition. Perform one baseline test.	1	1	A08294
19	One defective spark plug	Disconnect the high tension lead to one spark plug to simulate a bridged plug or failed lead.	1	10	A08321
20	Baseline	Perform one baseline test.	1*	1	A08357X

* = Tests that require temperature and flow measurements
X = Runs with temperature and flow measurements

Table A-1. Defect Vehicle Test Schedule and Defect Description (Continued)

Step No.	Type of Defect	Car Setup Procedure	Number of Tests This Step	Group No.	Olson Labs Run Number
		Car 1614170			
1	Baseline	Check CO at idle with secondary air disconnected upstream of the catalyst. Reconnect secondary air.	1	1	(A07907)[1] A07933
2	Rich idle	Richen idle system to either 5% CO before catalyst with secondary air disconnected or 100 rpm drop due to enrichment from lean best idle. Reconnect secondary air.	2	2	A07949 A07962
3	Rich idle	Richen idle system to 8% CO before catalyst with secondary air disconnected. Reconnect secondary air.	1	3	A08037
4	Baseline	Return idle mixture to original setting.	0		
5	Intermittent misfire	Introduce intermittent misfire (electronically short cylinders at random) at 10% misfire rate.	1*	4	A08156X
5A	Intermittent misfire	Introduce intermittent misfire (electronically short cylinders at random) at 10% misfire rate.	1*	4	A08190X
6	Intermittent misfire	Introduce intermittent misfire at 3% misfire rate.	2*	5	A08232X A08478X[2]
7	Baseline	Return ignition system to original condition and setting.	0		
8	No EGR	Deactivate EGR system.	2	6	A08243 A08255
9	Baseline	Set all parameters (CO, ignition, and EGR) to original baseline values and test.	1	1	A08257
10	Clogged air filter	Using a new air filter element, mask 95% of its flow area or sufficient to cause a 10-fold increase in Δp and then test vehicle. Leave the open zone of the element in two quadrants of the circumference. Δp to be read at 50-mph Key Mode loading. (Δp to be measured across element only — do not include Δp across air horn).	1*	7	A08265X

1 = Baseline replicate
2 = Run was made out of order; just prior to run A08504
* = Tests that require temperature and flow measurements
X = Runs with temperature and flow measurements

Table A-1. Defect Vehicle Test Schedule and Defect Description (Continued)

Step No.	Type of Defect	Car Setup Procedure	Number of Tests This Step	Group No.	Olson Labs Run Number
		Car 1614170 (Continued)			
11	Clogged air filter	Mask or otherwise chock the flow of air through the air filter element so as to obtain a 5-fold increase in Δp across the air filter at 50-mph Key Mode loading. (Δp to be measured across element only — do not include Δp across air horn).	2	7	A08280 A08292
12	Baseline	Return the car to the original condition.	0		
		Note: The following tests contain two or more defects:			
13	Intermittent misfire plus idle system too rich	Introduce intermittent misfire at 10% misfire rate as in step No. 5 plus richen up the idle system to 5% CO before catalyst with secondary air disconnected.	1*	8	A08306X
14	Intermittent misfire plus idle system too lean	Introduce intermittent misfire at 10% misfire rate as in step No. 5 plus lean out the idle system to 0.5% CO (or lowest CO level possible without misfire) before catalyst with secondary air disconnected.	1*	9	A08319X
15	Intermittent misfire plus EGR plugged	Deactivate the EGR system plus introduce intermittent misfire at 10% rate as in step No. 5.	1	10	A08343
16	Baseline	Return the vehicle to original condition. Run one baseline test.	1	1	A08376
17	Idle system too rich plus EGR not working	Deactivate EGR system plus richen idle system to 5% before catalyst with secondary air disconnected.	1	11	A08430
18	Idle system too rich plus ignition timing advanced	With 5% idle CO, advance basic idle timing 6°. EGR system operating normally.	2*	12	A08443X A08446X

* = Tests that require temperature and flow measurements
X = Runs with temperature and flow measurements

Table A-1. Defect Vehicle Test Schedule and Defect Description (Concluded)

Step No.	Type of Defect	Car Setup Procedure	Number of Tests This Step	Group No.	Olson Labs Run Number
		Car 1614170 (Continued)			
19	Idle system too rich plus ignition timing retarded	With 5% idle CO, retard basic idle timing by 6°.	1	13	A08457
20	Idle system too rich plus main fuel system too rich	Install main fuel jets that are three sizes too large as per car No. 2, step 6 and set idle CO at 5% level with secondary air disconnected.	1	14	A08470
21	Baseline	Return the vehicle to original condition. Run one baseline test.	1*	1	A08504X

* = Tests that require temperature and flow measurements
X = *Runs with temperature and flow measurements*

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(Please read Instructions on the reverse before completing)

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16. ABSTRACT

A series of statistical analyses was performed to determine the degree of "correlation" that exists between five specific short tests (STs) and the federal emission certification test procedure (FTP) for new vehicles. This work was performed to determine if "reasonable correlation with certification test procedures" exists; this is a condition precedent to the promulgation of regulations that impose the in-use warranty provisions of Sec. 207 (b) of the Clean Air Act of 1970 upon the motor vehicle manufacturers.

The basis for the analyses was ST and FTP test data from three vehicle fleets: (a) a catalyst-equipped experimental vehicle fleet (40 vehicles), (b) an in-use 1974 model year vehicle fleet (147 vehicles), and (c) a catalyst-equipped defect test fleet (5 vehicles). Each of the vehicles in these fleets was tested by the FTP and the following STs: (a) Federal Short Cycle, (b) New York/New Jersey (NY/NJ) Composite, (c) Clayton Key Mode, (d) Federal Three-Mode, and (e) Unloaded 2500 rpm. Hydrocarbon (HC) and carbon monoxide (CO) measurements were recorded with both laboratory analyzers and garage-type instruments for most of the volumetric tests. All oxides of nitrogen (NO_x) measurements were made with laboratory analyzers. Two different statistical analysis methods were used to assess "correlation"--a conventional correlation analysis and a contingency table analysis.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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