EPA Technical Report

Analysis of Humidity Effects on Fuel Economy in Response to a GM Request for CAFE Adjustments

by

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Introduction

GM submits that EPA's change in test humidity in 1977 (48 to 75 grains/lb) caused an estimated fuel economy penalty of .29 mpg on the EPA tests. This value was then adjusted by the fraction of tests EPA conducted for GM's CAFE. These data are shown in attachment E-II of their exhibits, and result in the requested adjustments of .16, .13, and .07 mpg to the GM CAFE values for 78, 79, and 80 MY.

Discussion

GM's penalty factor is based on a value they cited from the DOT/EPA Panel Report No. 6 (1/10/75) and from some of their own data on 19 vehicles from model years 75-79. The value cited from Report No. 6 (.069% decrease in MPG per one grain/lb humidity increase) was based on one study referenced in a letter from Ford Motor Co. to EPA in 1974. This letter in turn referenced an internal Ford program report entitled "Request for Barometric Pressure and Specific Humidity Adjustment Factors for Emissions and Fuel Economy Results, dated 7/30/74". Specific details could not be obtained regarding the test program, number of tests, confidence levels, or data source.

The same EPA/DOT report section also says, "Others have reported similar effects although some doubt that such an effect exists." This statement reflects the fact that the theoretical effect of increased humidity would be to enrichen the fuel/air mixture, thus reducing fuel economy. However, the actual occurrence of this theoretical effect is dependent on the calibration of the particular fuel system and the form of emission control used. Many late model control systems are insensitive to humidity differences because of feedback sensors that control the fuel/air ratio at the optimum value. In deriving a humidity factor from test data, one must carefully design the experiment to minimize the effects of other variables on fuel economy. Several studies and correlation programs over the past five years have shown both positive and negative effects, as well as a wide range of values for the sensitivity of fuel economy to humidity. The information obtained during these analyses are summarized in the Appendix to this report.

A specific study done by Juneja et. al. of GM in 1977 (SAE 770136) showed both positive and negative differences on five cars and the overall average was only half of what GM is now claiming as the proper adjustment.

GM estimates average MPG differences from test results where the humidity "<u>ranged</u>" from 30 to 90 grains/lb. Eight of the 19 tests reported were on 1975 MY vehicles. For the model years involved in the petition, only two data points are presented for each year. Several questions immediately come to mind regarding these data. How many tests were conducted on each vehicle and what are the confidence intervals for the data reported? Were the tests done just at 30 and 90 grains/lb and if so, does this represent the same sensitivity that might be obtained between 50 and 75 grains/lb? Why did GM only run two highway fuel economy data points, when the HWFE test accounts for 45% of the overall MPG value? How can two test vehicles per year properly represent the fleet used to determine the CAFE for 78, 79, and 80? Were these data collected specifically for this report, or were they retrieved from other sources? Hence, one can see that the data GM collected was not presented in sufficient detail to make an analysis of whether it is representative, appropriate, or statistically significant.

The entire subject of ambient correction factors to emissions or fuel economy results has been discussed previously between EPA and specific manufacturers. EPA's position has been to reject the concept for three reasons - vehicles do not operate in a world of constant ambient conditions, universal factors can not be equitably applied because they are constantly changing and are not precisely quantifiable, and finally, vehicles should be capable of meeting emissions and fuel economy standards throughout a normal range of ambient conditions.

GM's claim that the change in test humidity levels induced a change to their CAFE has been recognized by EPA. The humidity levels have been reset to 50 grains/lb. and are being controlled more precisely than in 1975. Nevertheless, EPA's review of GM's submission and other literature and data on this subject indicate that much more information and analysis are needed to assess whether a correction factor could be adequately determined and properly applied.

One source of data which was considered and analyzed was the EPA "Paired Data" test results file. This file contains the test results and ambient conditions for both the EPA and manufacturer's test on the same vehicle. These data were analyzed for MY 78, 79, 80, and 81 for both city and highway tests and were stratified into six groups (AMC, CHRY, FORD, GM, OTHERS, and ALL). Plots and regressions of fuel economy differences as a function of humidity differences for 6600 test pairs were obtained. The results indicated that the correlation between fuel economy and humidity differences is <u>very weak</u>. This is apparent from the high amount of scatter on the plots. The regressions, even though they have no statistical significance, show that it is possible to get both positive and negative effects on fuel economy from increases in humidity.

The paired data results incorporate almost all the variable differences one could encounter between two tests - labs, conditions, equipment, drivers, etc. Although it does not represent a well controlled experiment, nevertheless, it does represent a large data set from the actual certification and fuel economy tests which would be expected to reflect a directional and significant adverse impact on fuel economy values as a result of EPA's 1977 humidity increase. Based on the data analysis, EPA <u>cannot</u> state that their is <u>no effect</u> of humidity on the fuel economy of individual vehicles. At the same time, the analysis shows that a CAFE adjustment in which EPA could have any confidence cannot be quantified from the available data.

The entire concept of accepting manufacturer's data in lieu of EPA confirmatory tests under the abbreviated certification program is a change from the program of 1975. One assumes that the manufacturer can generate data that are essentially equivalent to EPA's official values. Hence, the concept of correction factors would have to also address the laboratory correlation aspects of testing at two facilities.

For example, data from MY81 tests (at EPA's reduced humidity levels) on GM vehicles show that GM humidity levels average about 7 grains/lb. higher than those at EPA. However, GM's fuel economy values have been and are still about 1.5% higher than EPA's results. Starting in the 1979 model year, EPA accepted data from GM's lab in lieu of confirmatory testing (which accounts for about 50% of the data used to generate CAFE values). GM failed to account for this "bonus" in its calculation of adjustment factors related to EPA's humidity change. Therefore, for the 79 and 80 model years, GM may have received a net CAFE bonus as a result of EPA's acceptance of GM laboratory data.

Conclusions/Recommendations

The data presented in support of GM's proposed adjustment to their CAFE for humidity cannot be assessed for validity and significance.

The confidence one can have in the universal nature of a correction factor is generally not sufficient to make predictive or corrective adjustments. In other words, some data would be grossly overcorrected and other results would be undercorrected.

The subject of ambient correction factors, their standardization, validity, feasibility, and magnitude should not be based on limited data of questionable representativeness. A change to EPA's practices in this area has significant implications for both emissions and fuel economy results for all manufacturers. A comprehensive analysis of all effects, both positive and negative, should be part of any such study. Even if an acceptable test program could be done, application of the data to other model years and control systems may not be valid.

APPENDIX

Fuel Economy Differences versus Humidity Differences

TABLE A – REGRESSION DATA FOR FUEL ECONOMY DIFFERENCES VERSUS DIFFERENCE IN ABSOLUTE HUMIDITY 1979 CALENDAR YEAR EPA PAIRED TEST RESULTS

DEPENDENT VARIABLE	TP	ITEM	10 AMC	20 CHRY	30 FORD	40 GM	50-660 OTHERS	ALL MFR
FTP	(2)	N	32	78	119	147	288	664
ΔMPG		m	-.39	1.19	1.90	1.31	.616	.34
		b	-.60	-.47	-.23	-.01	-.21	-.24
		R	.02	.13	.16	.10	.05	.03
%ΔMPG		m	-8.68	3.25	15.36	7.58	1.02	1.25
		b	-3.05	-3.16	-1.28	-.01	-.89	-1.37
		R	.08	.05	.21	.09	.01	.02
HWFE	(3)	N	15	70	99	142	245	571
ΔMPG		m	-2.6	-.88	2.24	1.12	-1.78	-2.18
		b	-.75	-.35	.26	.34	-.12	-.09
		R	.28	.08	.12	.06	.11	.15
%ΔMPG		m	-32.9	1.78	17.6	605	-15.3	-13.9
		b	-5.15	-1.91	2.36	1.96	-.17	-.26
		R	.35	.03	.15	.08	.21	.19

$Y = m\,\Delta K_H + b$

$\Delta K_H = (MFR - EPA)$ NO_x C.F.

$Y = \Delta MPG = (MFR - EPA)$

$Y = \%\Delta MPG = \frac{(MFR - EPA)}{EPA} \times 100\%$

94 GRAINS/LB = K_H @ 1.100
75 GRAINS/LB = K_H @ 1.000
51 GRAINS/LB = K_H @ .900
20 GRAINS/LB = K_H @ .800

TABLE B – REGRESSION DATA FOR FUEL ECONOMY DIFFERENCES VERSUS ABSOLUTE HUMIDITY DIFFERENCES FROM CY 1978 (MY=79) EPA PAIRED TEST RESULTS

DEPENDENT VARIABLE	TP	ITEM	10 AMC	20 CHRY	30 FORD	40 GM	50-660 OTHERS	ALL MFR
FTP	(2)	N		125	124	237	203	689
ΔMPG		m	NO DATA	-1.57	.81	-1.24	-3.93	-2.33
		b		-.26	-.13	.11	-.19	-.14
		R		.13	.06	.12	.22	.17
		N		126	126	238	203	693
%ΔMPG		m	NO DATA	-7.88	8.78	-8.52	-16.5	-11.6
		b		-1.53	.04	.65	-.71	-.53
		R		.11	.10	.12	.21	.16
HWFE	(3)	N		91	103	155	164	513
ΔMPG		m	NO DATA	-3.90	-1.67	.96	-4.11	-3.20
		b		-.19	.30	.59	.23	.22
		R		.18	.06	.05	.22	.16
		N		91	103	155	166	515
%ΔMPG		m	NO DATA	-15.4	-4.05	3.78	-16.8	-13.0
		b		.001	1.93	2.95	.81	1.25
		R		.20	.04	.04	.21	.16

$Y = mX + b$

$Y = \Delta MPG_{(MFR-EPA)}$ AND $\%\Delta MPG = \frac{(MFR-EPA)}{EPA} \times 100\%$

$X = \Delta K_H$ K_H = NO_x CORRECTION FACTOR

K_H	1.100	1.000	.900	.800	
HUMIDITY	94	75	51	20	GRAINS/LB

TABLE C - REGRESSION DATA FOR FUEL ECONOMY DIFFERENCES VERSUS ABSOLUTE HUMIDITY DIFFERENCES FROM CY 1977 (MY-78) EPA PAIRED TEST RESULTS

DEPENDENT VARIABLE	TP	ITEM	10 AMC	20 CHRY	30 FORD	40 GM	50-660 OTHERS	ALL MFR
FTP	(2)	N		84	154	84	33	355
ΔMPG		m	NO DATA	-1.68	2.16	-.26	-.266	-.66
		b		-.331	.137	-.104	.067	-.158
		R		.140	.125	.031	.028	.059
		N		84	155	85	33	357
%ΔMPG		m	NO DATA	-12.655	11.792	-3.50	2.86	-3.71
		b		-1.64	.854	-.854	-.383	-.831
		R		.168	.106	.056	.066	.052
HWFE	(3)	N		54	131	69	20	274
		m	NO DATA	-2.51	-.527	-.203	-8.51	-3.67
		b		-.367	.331	.278	.038	.042
		R		.101	.017	.013	.449	.165
		N		54	131	70	20	275
		m	NO DATA	-12.19	2.19	-1.97	-28.07	-10.83
		b		-.614	1.9	1.43	.454	.469
		R		.113	.018	.025	.496	.123

TABLE B - AVERAGE DIFFERENCES OF PAIRED TEST PARAMETERS FOR 1978 (MY80)

	10 AMC	20 CHRY	30 FORD	40 GM	50-660 OTHERS		ALL MFR
FTP							
N	36	82	134	178	322		752
DEL MPG	-.724	-.503	-.395	-.042	-.252		-.278
%DEL MPG	-3.51	-2.89	-2.13	-.145	-.723		-1.20
DEL K_H	-.014	-.006	-.053	-.0567	-.012		-.028
%DEL K_H	-1.34	-.458	-5.28	-5.66	-1.16		-2.78
DEL BARO	.217	-.167	.322	-.237	.324		.142
DEL HUM	-3	-2	-12	-14	-3		-7
HWFE							
N	34	76	123	180	323		736
DEL MPG	-.989	-.432	.268	.478	-.003		.07
%DEL MPG	-3.81	-1.53	1.35	1.87	.121		.395
DEL K_H	-.004	-.010	-.061	-.065	-.012		-.032
%DEL K_H	-.320	-.837	-6.06	-6.45	-1.26		-3.21
DEL BARO	.237	-.075	.350	-.240	.320		.151
DEL HUM	-1	-2	-15	-15	-3		-7

DEL = MFR - EPA

% DEL = [(MFR - EPA)/EPA] × 100%

HUM = GRAINS/LB HUMIDITY

K_H = NO_X CORRECTION FACTOR

TABLE B - AVERAGE DIFFERENCES OF PAIRED TEST PARAMETERS FOR 1978 (MY79)

	10 AMC	20 CHRY	30 FORD	40 GM	50-660 OTHERS		ALL
FTP							
N	58	138	183	294	366		1039
DEL MPG	-.12	-.23	-.19	.19	.05		.0008
%DEL MPG	-.48	-1.33	-.65	1.15	.58		.21
DEL K_H	—	-.0012	-.070	-.052	-.021		-.037
%DEL K_H	—	-.066	-6.94	-5.14	-2.18		-3.67
DEL BARO	—	-.073	.29	-.26	.47		.11
DEL HUM	—	00	-16.5	-12	-5		-9
HWFE							
N	42	102	150	213	364		875
DEL MPG	-.35	-.17	.42	.64	.48		.39
%DEL MPG	1.17	.02	2.18	3.05	1.74		1.90
DEL K_H	—	-.008	-.066	-.040	-.025		-.035
%DEL K_H	—	-.74	-6.37	-4.08	-2.50		-3.44
DEL BARO	—	-.069	.30	-.27	.45		.13
DEL HUM	—	-22	-15.5	-9	-6		-8

TABLE E - AVERAGE DIFFERENCES OF PAIRED TEST PARAMETERS FOR 1977 (MY78)

	10 AMC	20 CHRY	30 FORD	40 GM	50-660 OTHERS	ALL MFR
FTP						
N	74	187	258	275	386	1181
DEL MPG	.146	-.230	.061	.089	.052	-.018
%DEL MPG	1.11	-1.09	.583	-.617	.009	-.117
DEL K_H	NO DATA	-.005	-.085	-.051	-.021	-.052
%DEL K_H		-.455	-8.52	-5.27	-2.07	-5.25
DEL BARO		-.152	.329	-.208	.577	.134
DEL HUM		-1	-20	-12	-5	-12
HWFE						
N	59	149	218	243	340	1010
DEL MPG	.210	.003	.368	.232	.188	.212
%DEL MPG	1.23	.570	1.67	1.17	.739	1.05
DEL K_H	NO DATA	-.0013	.094	-.06	-.003	-.063
%DEL K_H		-1.19	-9.44	-5.93	-.10	-6.23
DEL BARO		-.089	.286	-.208	.72	.132
DEL HUM		-3	-23	-14	-1	-15

TABLE G - AVERAGE SLOPE OF REGRESSIONS
Δ, %Δ MPG VS ΔKH

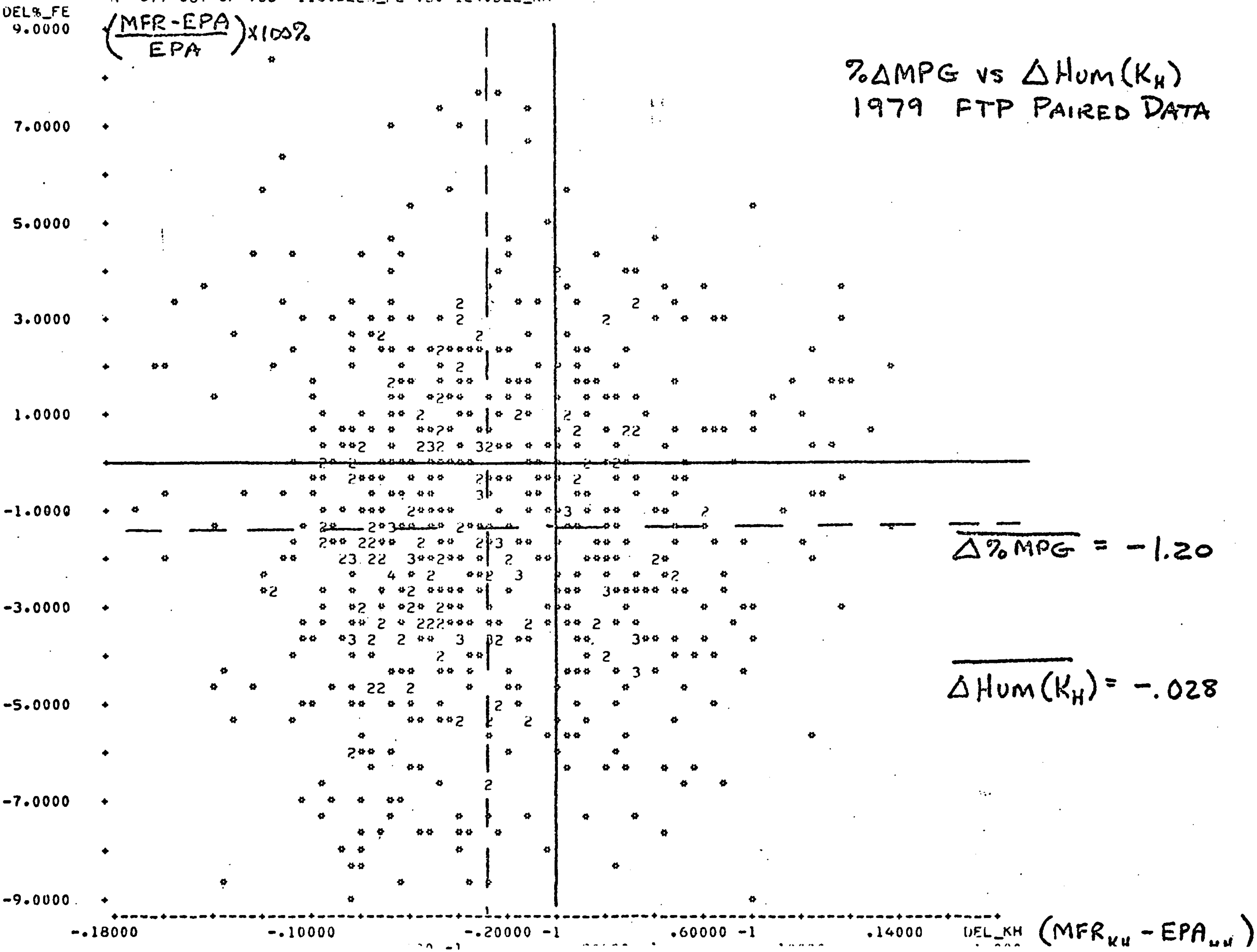
		FTP			HWFE	
		Δ MPG	%ΔMPG		ΔMPG	%ΔMPG
1977 = MY78	N			N		
AMC	—	—	—	—	—	—
CHRY	84	-1.68	-12.7	55	-2.51	-12.2
FORD	156	2.16	11.8	131	-.53	2.2
GM	86	-.26	-3.50	70	-.20	-2.0
OTHERS	33	-.27	2.86	20	-8.51	-28.1
ALL	358	-.66	-3.71	276	-3.67	-10.8
1978 = MY79						
AMC	—	—	—	—	—	—
CHRY	127	-1.57	-7.88	91	-3.90	-15.4
FORD	127	.81	8.78	103	-1.67	-4.05
GM	238	-1.24	-8.52	155	.96	3.78
OTHERS	203	-3.93	-16.5	166	-4.11	-16.8
ALL	695	-2.33	-11.6	515	-3.20	-13.0
1979 = MY80						
AMC	35	-.39	-8.68	22	-2.60	-32.9
CHRY	84	1.19	3.25	77	-.88	1.78
FORD	125	1.90	15.36	115	2.24	17.6
GM	153	1.31	7.58	153	1.12	1.65
OTHERS	314	.62	1.02	294	-1.78	-15.3
ALL	712	.34	1.25	661	-2.18	-13.9
AVERAGE (WT'D)	1769	-.91	-4.81	1452	-2.82	-13.0
IN TERMS OF PER GR/LB	—	-.0038	-.020	—	-.0118	-.054

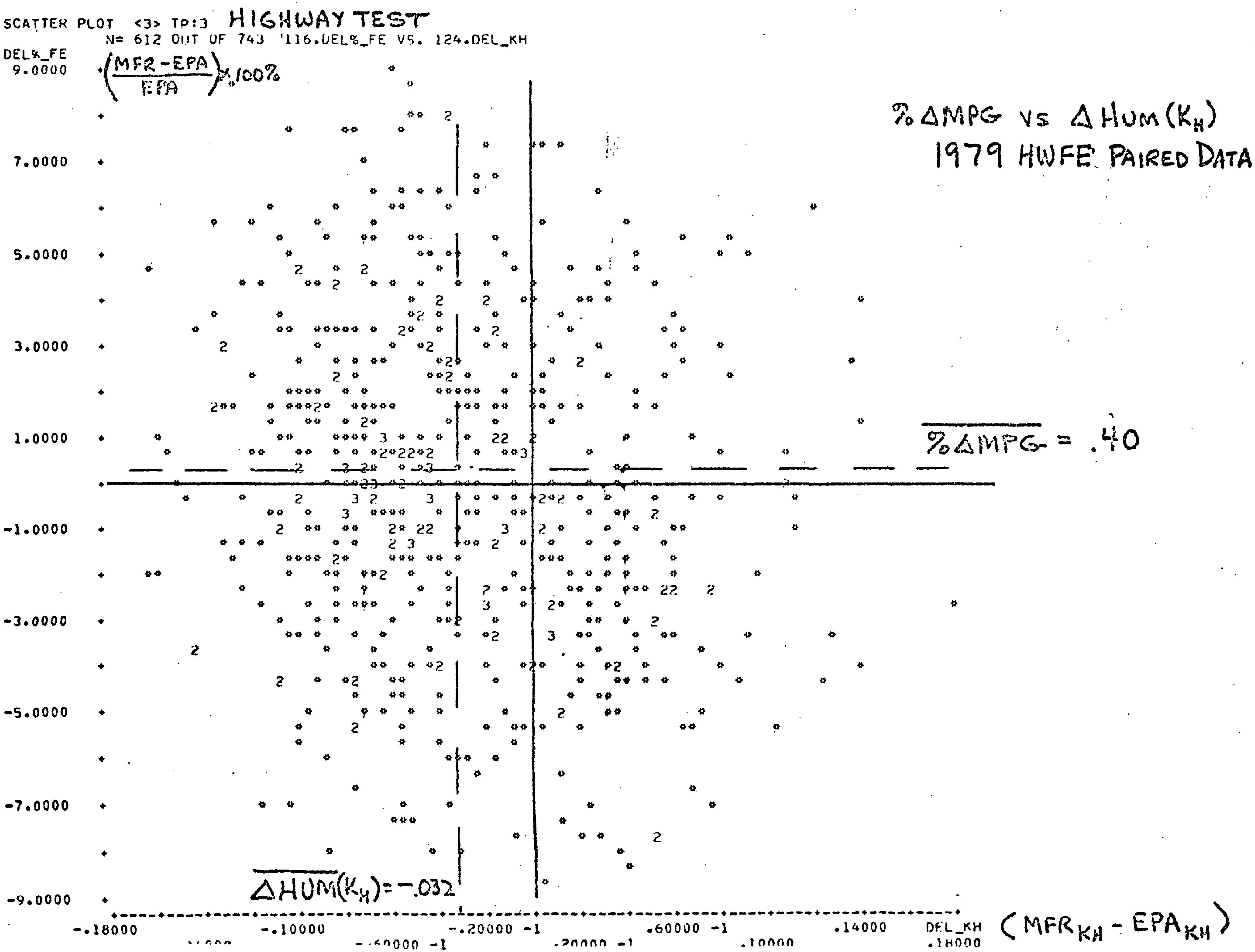
GM submits this is -.069

<SCATTER BYSTRATA VAR=116,124 CASES=ALL STRAT=V16 INTERVAL=(-9,9);(-.18,.18)>

SCATTER PLOT <2> TP:2 CITY TEST

N= 677 OUT OF 763 116.DEL%_FE VS. 124.DEL_KH




SCATTER PLOT <3> TP:3 HIGHWAY TEST
N= 612 OUT OF 743 '116.DEL%_FE VS. 124.DEL_KH
DEL%_FE
(MFR-EPA / EPA) × 100%
%ΔMPG vs ΔHum(K_H)
1979 HWFE PAIRED DATA
%ΔMPG = .40
ΔHUM(K_H) = -.032
9.0000
7.0000
5.0000
3.0000
1.0000
-1.0000
-3.0000
-5.0000
-7.0000
-9.0000
-.18000
-.10000
-.20000 -1
.60000 -1
.14000
DEL_KH
-.60000 -1
.20000 -1
.10000
.18000
(MFR_KH - EPA_KH)