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Technical Report

Assessment of the Hot Start Fuel Economy Effects of a New CVS Exhaust Connector Pipe Design

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Background

In June of 1985, the EPA-MVEL initiated a program to convert the EOD, fixed length CVS exhaust connector pipe to a variable length design, which is described in Equipment/Procedure Change Notice No. 64. Prior to the usage of these new style exhaust connectors, the Facility Support Branch performed a series of checks on each new connector. These tests included a bench static pressure leak check, a propane injection test with each new connector, and emissions and fuel economy verification tests using EOD's Volvo REPCA. By September, all EOD CVS's had been converted to the new design.

Although the REPCA tests permitted a comparison of CVS results obtained with the new system to results obtained with the old system, the REPCA data were slow to accumulate due to the heavy test schedule of Certification and In-use vehicles. Consequently, as the testing load slackened, it was determined that it would be meaningful to run a series of A-B type tests comparing the new and old exhaust collection systems.

It was thought that the change to the new style connector pipes might reduce an apparent carbon balance fuel economy offset between EPA and the manufacturers, particularily General Motors. These offsets were first observed early in 1985.

Program Design

The test program consisted of A-B type fuel economy tests with a repeatable vehicle using CVS's 21C, 22C, 29C, and 25C. Each CVS was used with two different connector pipes - one set of tests was run with the CVS' new pipe and one set was run with the old connector pipe from CVS 29C. The other elements of the test design included:

Vehicle - The test vehicle was a GM repeatable vehicle, a 1.8 liter, four cylinder, TBI Pontiac J-2000 equipped with a fuel flow meter, torque wheels, and fifth wheel distance pickup.

Driver - The same EPA driver drove a particular test sequence, but three different drivers were used during the course of the program.

Prep - The same tank of test fuel was used for all tests except the last set when it was necessary to add additional fuel. Each test sequence was started by warming up the vehicle and dynamometer for 15 minutes at 50 mph before the first test, with additional warm-up for 3 minutes at 50 mph preceding each LA-4.

Sequence - A daily test sequence consisted of a series of six hot start LA-4 (two bags) dynamometer tests, while changing the exhaust connector pipe after each LA-4. Two test sequences started with the old system in place, and two test sequences started with the new system in place. Volumetric fuel consumption, wheel torque/horsepower, and distance, measured in roll-feet, were recorded for each phase of the LA-4 cycles.

Results

This study, conducted between August 16 and August 21, showed a reduction in composite hot start LA-4 fuel economy in the range of 0.6 to 0.8 percent. An analysis of the hot start fuel economy effects is summarized in Table 1. Tables A-1 through A-4 and Figures A-1 through A-6 in the Appendix present detailed summaries of the bag and composite fuel economy results.

Table 1 is a summary of the overall average percent differences for phase 1, phase 2, and composite LA-4 results. The average percent difference between carbon balance and volumetric fuel economy is given for the new and old CVS exhaust connectors in columns one and two, respectively. In Table 1, the percentages -0.9, -1.0, and -0.8 are the overall changes in carbon balance versus volumetric fuel economy for phase 1, phase 2, and the composite LA-4 results, respectively. The last column summarizes the fuel economy effect based on the change in carbon balance fuel economy for the two types of exhaust connectors.

Because carbon balance and volumetric fuel economy are determined simultaneously, the overall carbon balance vs. metered differences for phase 1, phase 2, and composite results from the new and old connector pipes are determined by averaging the 12 individual test pair differences in each configuration.

By nature of the experimental design, old versus new comparisons could not be run simultaneously, and thus they are not paired results. Therefore, the overall percent differences in carbon balance fuel economy between the old and new connectors, shown in column four of Table 1, are calculated by taking the percent difference between the two grand means of carbon balance fuel economy.

The fuel economy effect is larger using the change in carbon balance versus metered fuel economy comparisons, although either method provides a valid means of estimating the fuel economy impact of the change in exhaust connectors. Thus, a reasonable estimate of the LA-4 fuel economy impact is in the range of -0.6 to -0.8 percent.

Tables A-1 through A-4 in the Appendix present the raw carbon balance and metered fuel economy data for the individual tests. In these figures, the numbers 1-6 to left of the phase 1 carbon balance data indicate the order in which the fuel economy measurements were obtained. Inspection of Tables A-1 through A-4 shows that fuel economy tests using CVS's at D001 and D006 were started with the new connector pipe in place, while tests on D002 and D005 were begun with the old connector in place.

In Figures A-1 through A-3, the carbon balance versus volumetric percent differences obtained with the old and new sampling systems are presented as a function of the actual test sequence. This information is summarized for composite, phase 1, and phase 2 results, respectively. Figures A-4 through A-6 of the Appendix are plots of the individual carbon balance and volumetric fuel economy for the composite, phase 1, and phase 2 results, respectively, versus the test sequence order.

Discussion

All of the test data were closely examined to verify their validity and to check for effects other than those which may be attributed to the change in the sampling system. The following observations are made with respect to wheel torque and horsepower, exhaust emissions, and fuel economy.

Wheel torque and horsepower:

The same driver drove all six tests once a particular test sequence was started, but three different drivers were used during the four days of testing. Nevertheless, the wheel torque and horsepower measurements were very precise for a given test day, and very repeatable among the four dynamometers. Positive and negative torque repeated within 2 percent during phase 1 and 2 dynamometer operation. Integrated horsepower repeated within 2 percent for all test phases except phase 1 where negative horsepower repeated within 7 percent. These levels of torque and horsepower measurement precision are well within the range of good repeatability for EPA's Clayton dynamometers.

Emissions:

No change in HC, CO, or NOx emissions were observed as the sampling system was switched between the new and the old configurations. HC emissions varied about $\pm$ 3 percent around a composite mean of 0.063 g/mi. Composite CO emissions averaged 1.56 g/mi with a range of $\pm$6 percent. Composite NOx emissions averaged 0.53 g/mi and varied $\pm$4 percent around this value. These emission results demonstrate very good test precision.

Fuel Economy:

Figures A-4 and A-5 clearly demonstrate that the fuel economy was lower on the first test of each six test sequence, despite a 15 minute warm-up at 50 mph. Figure A-5 indicates that this was a phenomenon of the phase 1 test results, but this effect also caused a decrease in the composite fuel economy (Figure A-4). The increasing fuel economy as a function of time is likely due to tire and lubricant warm-up effects, and possibly influenced by driver familiarity with the vehicle after the first phase of the first test. Although this warm-up effect confounds the interpretation of the old versus new sample system results, the experimental design mitigated its impact. This is true because two of the four dynamometer test sequences began with the old connector pipe in place, and two test sequences were started with the new connector. Even when the first test was deleted from each series of dynamometer tests, the effect of the change to the new system was the same - composite fuel economy decreased 0.6 percent.

Figures A-4 through A-6 show that metered, and to a lesser degree, carbon balance fuel economy, increased over time. This effect was small and very gradual, therefore, it was not expected to affect the findings summarized in Table 1.

Summary

The overall composite difference of -0.6 to -0.8 percent provides an estimate of the change in fuel economy attributable to the new exhaust sampling system. The effect of the sampling system with respect to regulated emissions was not observable.

The limitations of this program must be understood when extrapolating these results to FTP and HFET fuel economy results. The limitations are:

1. A single, old type exhaust connector was used for all tests.
2. The real fuel economy effect will be a function of the particular vehicle (this vehicle may have over- or understated the effect).
3. The hot start effects which were estimated in this program are not directly relatable to cold start fuel economy.
4. The fuel economy effect of the new connectors will likely change as the new connectors wear.

Recommendations for Future Actions

1. Continue to monitor the carbon balance and volumetric fuel economy data from the Volvo REPCA to assess the long term effect of the change in the exhaust sampling system.

2. Concentrate on examining the CVS sampling system design and calibration practices as possible explanations for the difference between EPA and GM carbon balance fuel economy measurements.

Table 1

Fuel Economy Effects [1]
New vs. Old Exhaust Connectors, % Difference

	New CB-New M [2] / New M		Old CB-Old M / Old M		Fuel Economy, Δ CB vs. M	New CB-Old CB / Old CB
Phase 1	(2.1	-	3.0)	=	-0.9	-0.5
Phase 2	(3.3	-	4.3)	=	-1.0	-0.8
Composite	(2.5	-	3.3)	=	-0.8	-0.6

[1] Based on 24 tests on 4 dynamometers; 12 with old connector, 12 with new connectors.

[2] CB = Carbon balance fuel economy, mpg.
M = Metered fuel economy, mpg.

APPENDIX

Table A-1
Dyno 1 (CVS 21C) Fuel Economy Results
New vs. Old Exhaust Connectors, mpg

	Sequence	Old CB	Old M	Sequence	New CB	New M
Phase 1	2	29.4	28.5	1	28.6	28.3
	4	29.0	28.4	3	28.9	28.5
	6	29.3	28.6	5	28.9	28.7
Phase 2		26.7	25.9		26.8	26.3
		27.0	26.2		26.7	26.1
		26.7	25.9		26.5	26.0
Composite		27.9	27.2		27.7	27.3
		27.9	27.3		27.8	27.3
		27.9	27.3		27.7	27.3

Table A-2
Dyno 2 (CVS 22C) Fuel Economy Results
New vs. Old Exhaust Connectors, mpg

	Old			New		
	Sequence	CB	M	Sequence	CB	M
Phase 1	1	28.6	28.0	2	29.1	28.3
	3	29.4	28.5	4	29.1	28.5
	5	29.5	28.4	6	29.3	28.6
Phase 2		26.7	25.9		26.4	25.8
		26.6	25.7		26.4	25.7
		26.8	25.8		27.0	26.1
Composite		27.6	26.9		27.7	27.0
		27.9	27.1		27.6	27.1
		28.0	27.1		28.0	27.4

Table A-3
Dyno 5 (CVS 29C) Fuel Economy Results
New vs. Old Exhaust Connectors, mpg

	Old			New		
	Sequence	CB	M	Sequence	CB	M
Phase 1	1	29.2	28.1	2	29.2	28.4
	3	29.3	28.3	4	29.3	28.4
	5	29.5	28.3	6	29.4	28.4
Phase 2		27.0	25.7		27.0	25.6
		27.3	25.7		27.2	25.8
		27.2	25.7		27.0	26.1
Composite		28.0	26.9		28.0	27.0
		28.2	27.0		28.2	27.1
		28.3	27.0		28.1	27.0

Table A-4
Dyno 6 (CVS 25C) Fuel Economy Results
New vs. Old Exhaust Connectors, mpg

	Old			New		
	Sequence	CB	M	Sequence	CB	M
Phase 1	2	28.8	27.9	1	28.7	27.8
	4	28.5	28.0	3	28.8	28.3
	6	29.1	28.3	5	28.6	28.4
Phase 2		26.7	25.6		26.2	25.3
		26.8	25.5		26.4	25.6
		27.2	25.8		26.6	25.7
Composite		27.7	26.7		27.3	26.6
		27.6	26.8		27.5	26.9
		28.0	27.1		27.5	27.1

FIGURE A-1

EPA SITE HARDWARE EVALUATION - 1985
"OLD" vs "NEW" - DYNOS 1, 2, 5 & 6

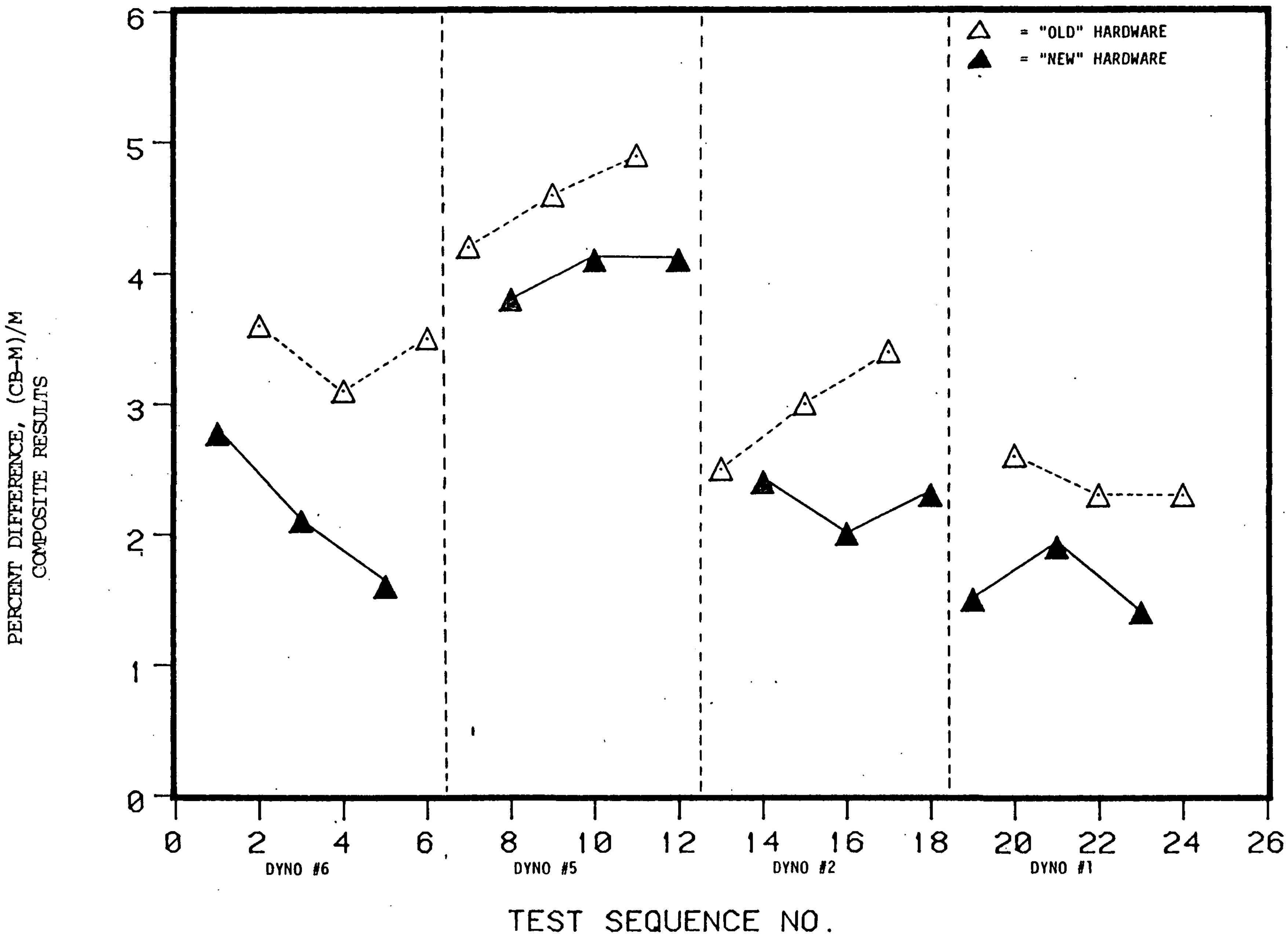
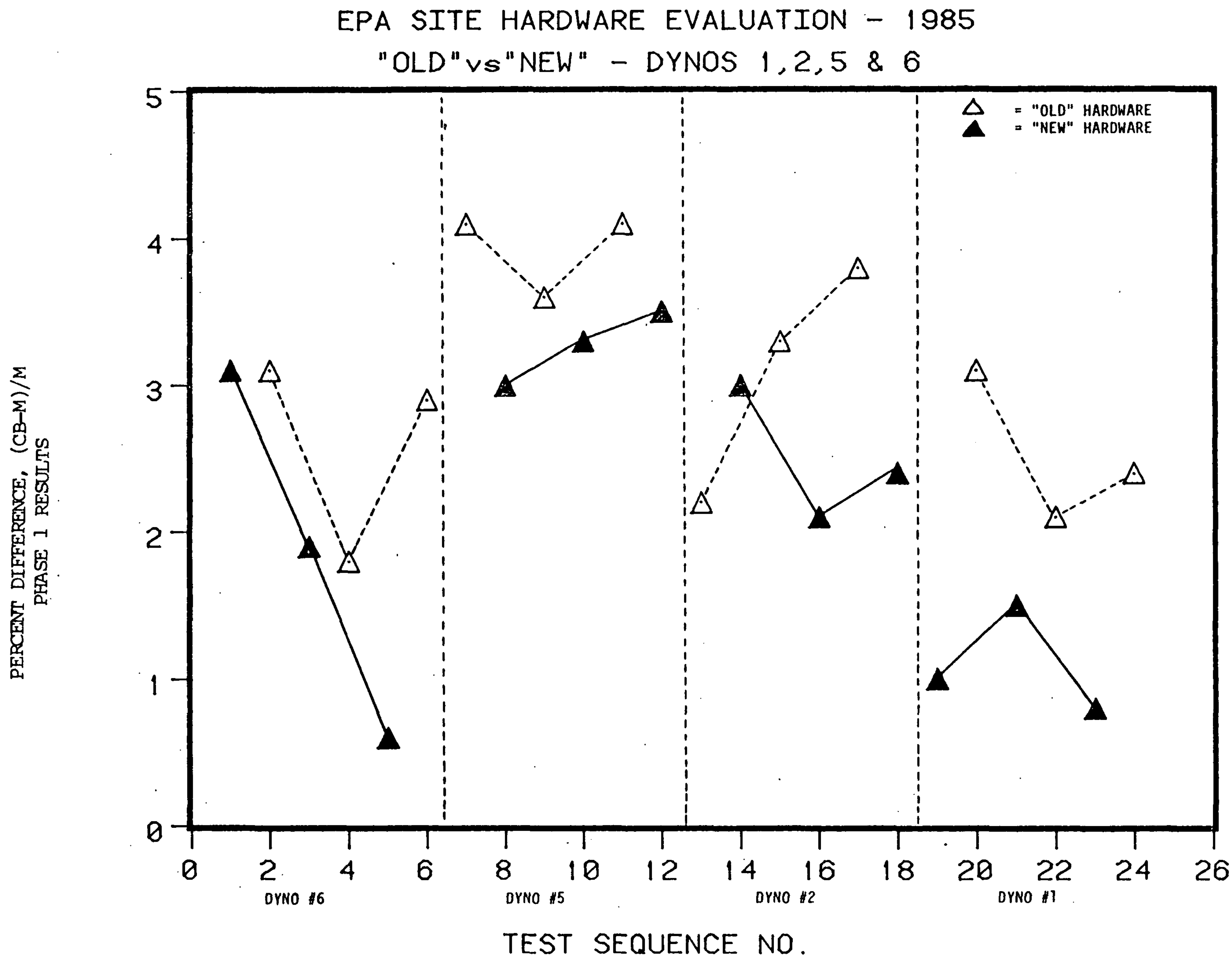


Figure A-2



EPA SITE HARDWARE EVALUATION - 1985
"OLD"vs"NEW" - DYNOS 1,2,5 & 6
= "OLD" HARDWARE
= "NEW" HARDWARE
PERCENT DIFFERENCE, (CB-M)/M
PHASE 1 RESULTS
0
1
2
3
4
5
0
2
4
6
8
10
12
14
16
18
20
22
24
26
DYNO #6
DYNO #5
DYNO #2
DYNO #1
TEST SEQUENCE NO.

Figure A-3

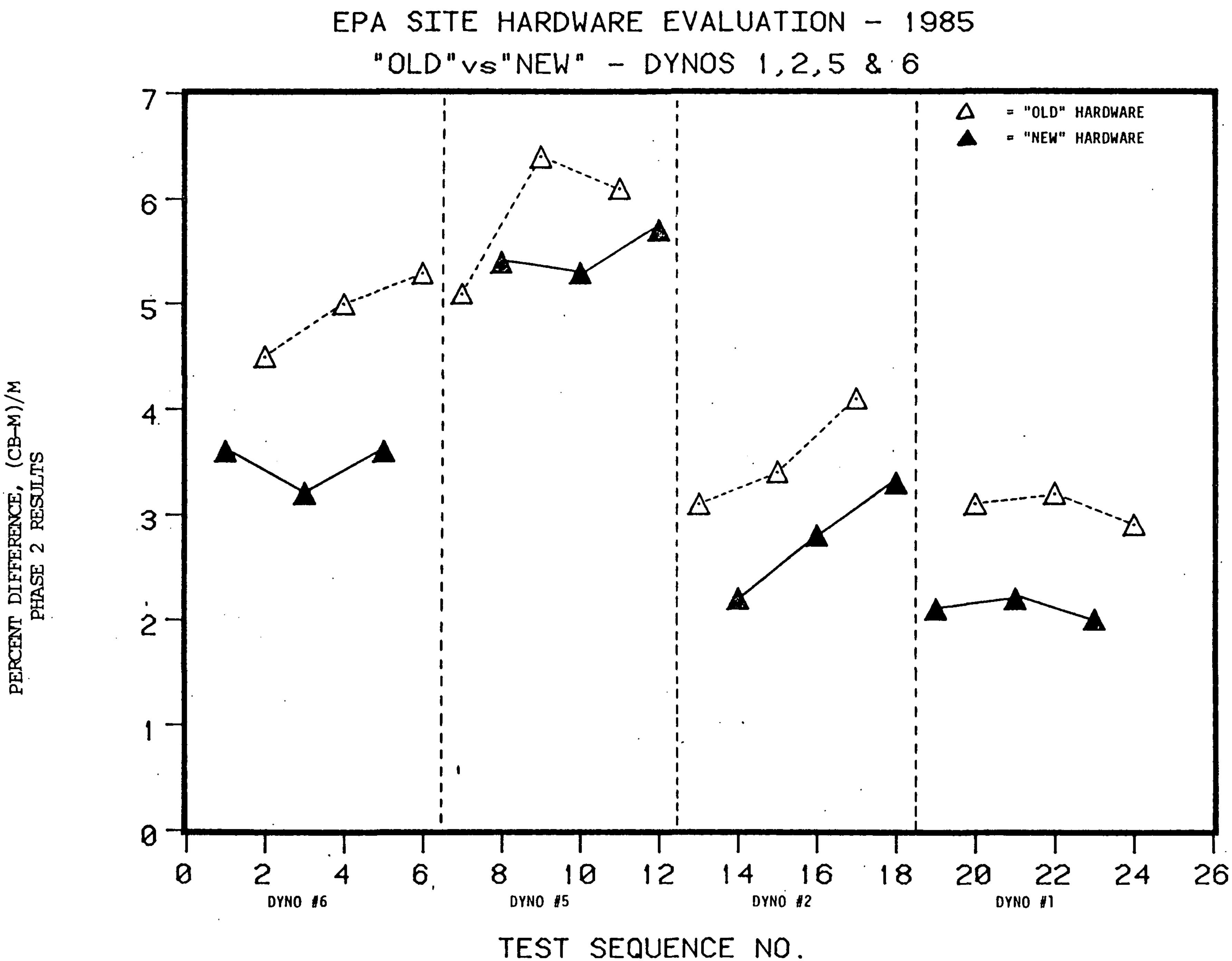
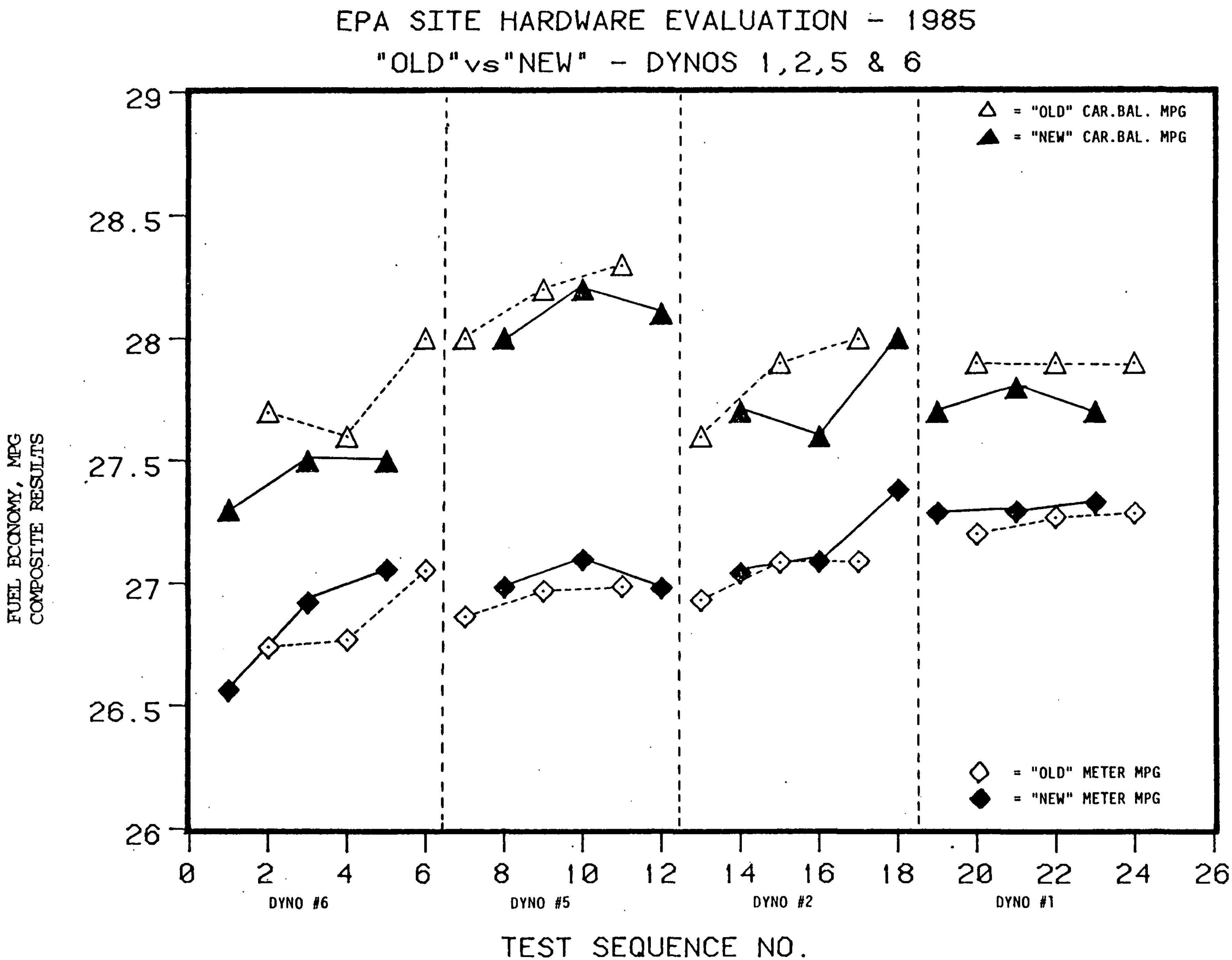

EPA SITE HARDWARE EVALUATION - 1985
"OLD"vs"NEW" - DYNOS 1,2,5 & 6
PERCENT DIFFERENCE, (CB-M)/M
PHASE 2 RESULTS
△ = "OLD" HARDWARE
▲ = "NEW" HARDWARE
0
1
2
3
4
5
6
7
0
2
4
6
8
10
12
14
16
18
20
22
24
26
DYNO #6
DYNO #5
DYNO #2
DYNO #1
TEST SEQUENCE NO.

Figure A-4



EPA SITE HARDWARE EVALUATION - 1985
"OLD"vs"NEW" - DYNOS 1,2,5 & 6
= "OLD" CAR.BAL. MPG
= "NEW" CAR.BAL. MPG
= "OLD" METER MPG
= "NEW" METER MPG
FUEL ECONOMY, MPG
COMPOSITE RESULTS
29
28.5
28
27.5
27
26.5
26
0
2
4
6
8
10
12
14
16
18
20
22
24
26
DYNO #6
DYNO #5
DYNO #2
DYNO #1
TEST SEQUENCE NO.

Figure A-5

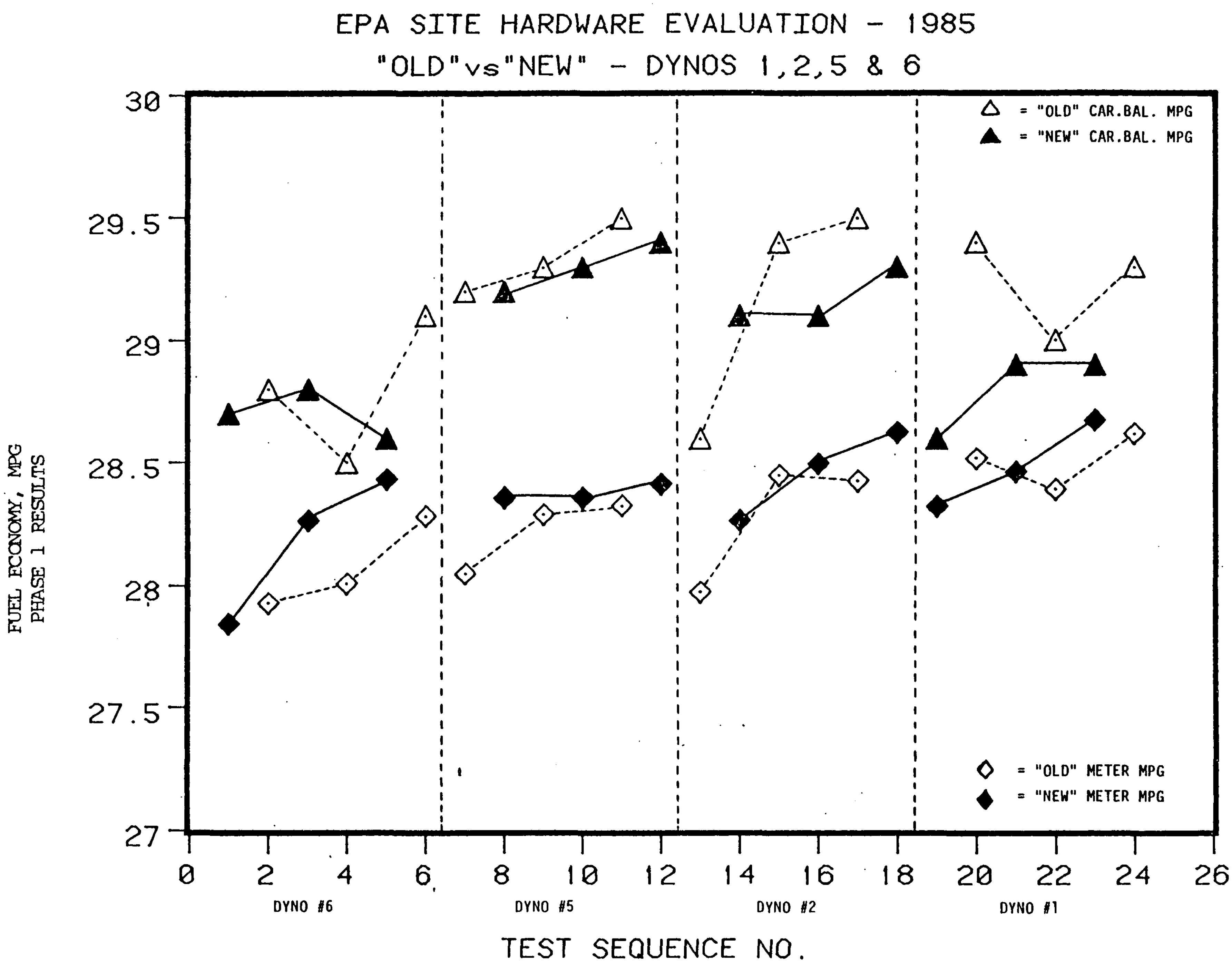
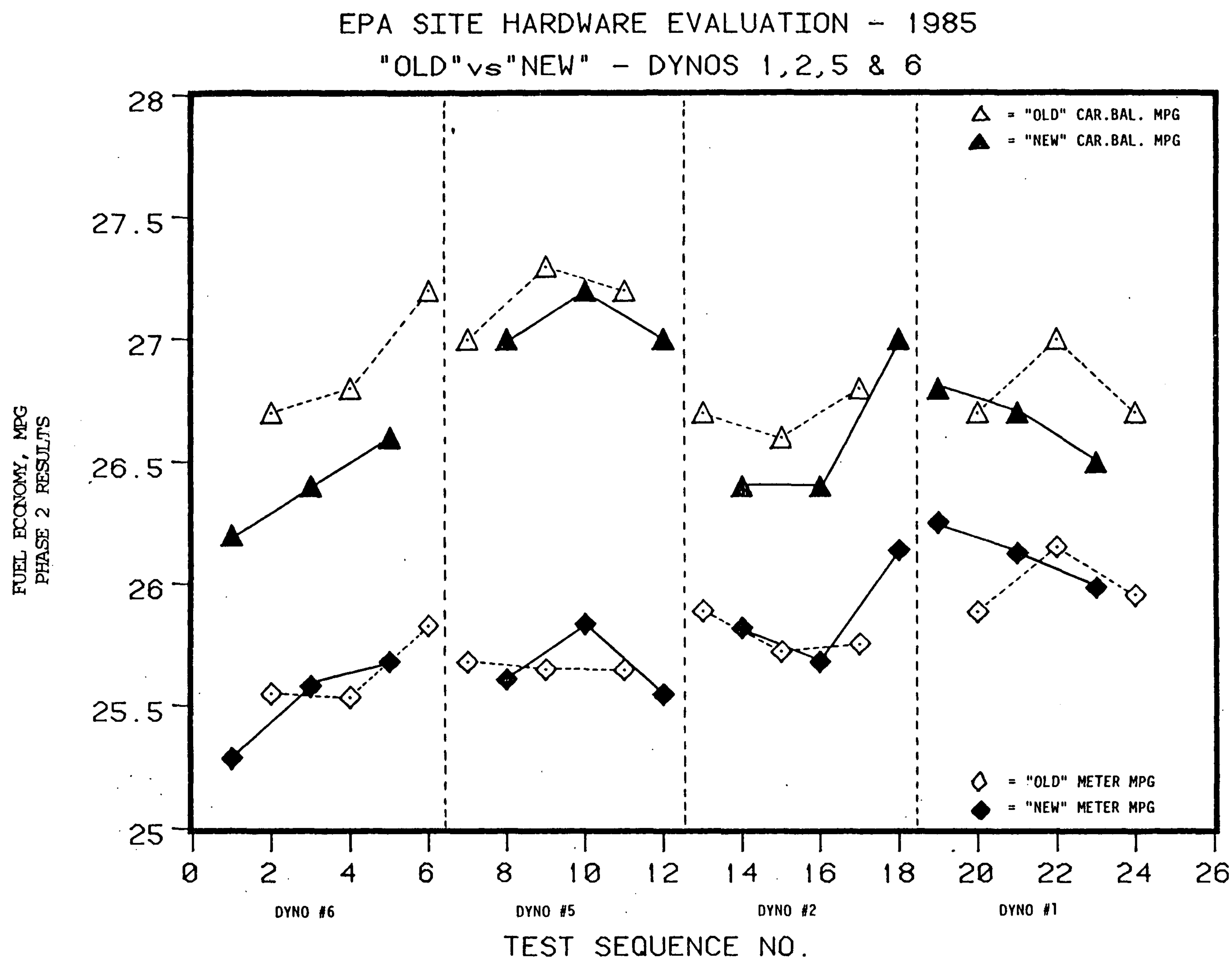

EPA SITE HARDWARE EVALUATION - 1985
"OLD"vs"NEW" - DYNOS 1,2,5 & 6
= "OLD" CAR.BAL. MPG
= "NEW" CAR.BAL. MPG
= "OLD" METER MPG
= "NEW" METER MPG
FUEL ECONOMY, MPG
PHASE 1 RESULTS
30
29.5
29
28.5
28
27.5
27
0
2
4
6
8
10
12
14
16
18
20
22
24
26
DYNO #6
DYNO #5
DYNO #2
DYNO #1
TEST SEQUENCE NO.

Figure A-6


EPA SITE HARDWARE EVALUATION - 1985
"OLD"vs"NEW" - DYNOS 1,2,5 & 6
= "OLD" CAR.BAL. MPG
= "NEW" CAR.BAL. MPG
= "OLD" METER MPG
= "NEW" METER MPG
FUEL ECONOMY, MPG
PHASE 2 RESULTS
28
27.5
27
26.5
26
25.5
25
0
2
4
6
8
10
12
14
16
18
20
22
24
26
DYNO #6
DYNO #5
DYNO #2
DYNO #1
TEST SEQUENCE NO.